... OF THE INTERIOR, CANADA

..., MINISTER — W. W. CORY, DEPUTY MINISTER

RECLAMATION SERVICE
E. F. DRAKE, DIRECTOR

IRRIGATION SERIES
Bulletin No. 6

IRRIGATION PRACTICE AND WATER REQUIREMENTS FOR CROPS IN ALBERTA

ERRATA

Page 5 '.wo models' in last paragraph should read, 1 model.
Page 26 In the 7th and 8th paragraphs 'June' should read, June 1.
Page 28 First line, fourth patagraph, 'fine and' should rea... fine sand.
Page 29 In the last line of the 4th patagraph, 'a cut binder' should read, a five-foot cut binder.
Page 48 Second last line should read, make up the average duty of 1. ... feet, 81 are on alfalfa, 26 on wheat, 15 on oats, 12 on timothy and 6 on barley.
Page 49 Table ..., the total depth received for wheat in 1916 should be 1.73 not 1.72.
Table 5, mean temp for Apr 1914 should be 42.4
Ave. max yield of patatoes at Ronalane is 356.

OTTAWA
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PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
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DEPARTMENT OF THE INTERIOR, CANADA

HON. CHARLES STEWART, MINISTER - W. W. CORY, DEPUTY MINISTER

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IRRIGATION PRACTICE AND WATER REQUIREMENTS FOR CROPS IN ALBERTA

BY

W. H. SNELSON, A.M.E.I.C.
Senior Irrigation Specialist

OTTAWA
F. A. ACLAND
PRINTER TO THE KING'S MOST EXCELLENT MAJESTY
1922

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SECTION 1

PRACTICAL INFORMATION FOR BEGINNERS IN IRRIGATION

Levelling the Land.—The first, and probably the most important, work which confronts the farmer who is preparing to irrigate his fields, is levelling the land. Too much emphasis cannot be placed on the necessity of having the fields properly graded and levelled before laying out the irrigation laterals. Properly levelled lands aid in the economical and uniform application of water, lessen the danger from over- or under-irrigation of any portion of the field, and enhance the prospect of good yields.

Much of the discouragement met with in a newly irrigated district is caused by poor crop yields from fields which, on account of their roughness, could not be uniformly covered with water. In many of the older districts large expenditures per acre have been made in levelling knolls, filling up depressions, and giving the field a uniformly graded surface. A farmer will never regret money spent on work of this nature.

The first and most important operation in levelling the land is done with the Fresno scraper. With it, all prominent and unirrigable knolls are cut off and deposited in adjacent depressions. As this implement is familiar to all, no description of it will be given here.

Other implements used in levelling land are the "Buck scraper" and the "Float"—two models of the former and one of the latter being shown in accompanying illustrations.

Fresno Scraper.

The California model buck scraper is made in widths varying from ten to twenty feet, and requires from six to twelve horses. This scraper operates on much the same principle as the Fresno, except that it is much wider and will do the work more rapidly. The cut, however, is not so deep. The long handle behind enables the operator to accurately gauge the depth of cutting when removing the earth from a knoll and to spread the load evenly when dumping.

The California Model Buck Scraper.

The float is used after the heavier grading work has been completed with the scraper and after the land has been ploughed to smooth the surface. Floating must be done when the soil is rather dry as it cannot be done well when the soil is wet. A good float will both pulverize and pack the soil and is an indispensable implement on any irrigated farm. It should be made along the lines shown in the accompanying plan. The side members or runners should be made of two-inch by twelve-inch planks, twenty feet long. The centre and rear cross-pieces should be made from two-inch by twelve-inch planks. The front cross-piece should be made from a two-inch by eight-inch plank which, when in place, should be flush with the tops of the side runners, leaving a space of four inches underneath its bottom edge to permit of the passage of clods and rubbish. The centre piece should stand perpendicular to the ground and be placed eight feet behind the front cross-piece. The rear cross-piece should be placed seven feet behind the centre one and about five feet from the ends of the side members, and should have a slant of about fifteen degrees from the perpendicular. The bottom of the centre cross-piece should be shod with iron, to form a cutting edge for shaving off small knolls. Half-inch iron rods should be placed through the float behind each cross-piece and drawn tight with bolts and washers. The float should be braced laterally across the top with pieces of two- by four-inch timber. Bolt lugs for attaching a pulling chain should be provided on each side of the float near the front. It should be borne in mind that it is the centre cross-piece which does most of the work, as in a carpenter's plane. In all cases well-seasoned wood, free from knots or cracks, should be used. The front cross-piece acts merely as a brace; the back one as a general "smoother out" of lumps. It is important that the side members extend at least five feet behind the back cross-piece. The value of this arrangement will become apparent when the first ditch or hole is

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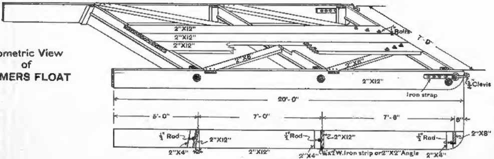


Isometric View
of
FARMERS FLOAT

Section

crossed. The back cross-piece will be carrying some dirt which it will let down into the hole, the extension runners meanwhile preventing the cross-piece from following the dirt down, as it would tend to do if the runners did not extend beyond the rear cross-piece.

Fields should be floated both ways. Good floating ensures even depth of planting and a fine seed bed. A float of the above length and six to seven feet wide is a good load for four horses.

A Fordson tractor will pull a seven-foot wide float, weighted with two to three hundred pounds of earth in sacks. If land is very loose the tractor will need extension ribs on the wheels.

Laying out the Farm Laterals.—Considerable areas of the irrigable lands in Alberta are rather flat, some quarter-sections having only a foot or so difference in elevation between the headgate box and the farthest point to which water must be conveyed in the farm laterals. In these flat lands it is often necessary to run the laterals on a very flat grade in order that all of the land may be covered with water. To do this requires accurate levelling. Several different makes of small levelling instruments have been put on the market within recent years, some of which are not sufficiently accurate for work on very flat lands. Much more satisfactory results are obtained when the laterals are located with an engineer's level.

Use of the Level.—The level should be set up and levelled in the following manner. Carefully screw the instrument on the tripod, which has been placed in position. Place the telescope diagonally across either pair of screws and bring the bubble to the centre of the tube by means of the thumb-screws, care being taken that the screws are moved in opposite directions; then turn the telescope diagonally across the other pair of screws and bring the bubble again to the centre. This operation should be repeated until the bubble will remain in the centre during a complete horizontal revolution of the telescope.

Place the level rod with its bottom at the elevation of the water surface in the main supply ditch or headgate box, care being taken to have the rod plumb. Then sight through the telescope and note the figure intercepted by the horizontal cross-hair. For example, we shall assume that the cross-hair intercepts the figure 4.8 feet, and that it has been decided to run the ditch on a grade of one-tenth of a foot per one hundred feet. Now measure off one hundred feet from the starting point, having one man hold the front end of the measuring tape or chain, together with the level rod. A second man should hold the rear end of the tape. The rod is then held up by the leading man for a reading. As the ditch is to fall one-tenth of a foot per one hundred feet, and a reading of 4.8 feet has already been observed at the starting point or station zero, 4.9 feet must be read for station one. By taking a sight on the rod, for instance, a reading of 4.7 feet may be observed; this indicates that the rod is being held at too high an elevation and it should be moved slightly downhill until the cross-hair of the telescope intercepts 4.9 on the rod. Conversely, if a reading of 5.1 feet is observed, the rod should be moved uphill until the 4.9 figure on the rod is intercepted.

To establish station two, one hundred feet farther ahead, place the rod to read 5.0 feet, indicating a fall of 0.1 foot from station one. Repeat this operation until four or five stations have been established, when the instrument must be moved ahead approximately four or five hundred feet beyond the last station established. Then set up and level the instrument and take a reading on the rod which has remained at the last point established. The reading may now be 5.6 feet, and the station to be established one hundred feet ahead must read 5.7 feet, the next 5.8 feet, and so on.

Proper Gradient for Farm Laterals.—The average farm lateral as made with a plough and "V" ditcher is usually run on a grade of 0.1 to 0.2 foot per one hundred feet. Where it is necessary to keep the ditch "up" to reach some certain point, flat grades, as low as 0.02 foot per one hundred feet are used. With these flat grades,

however, the velocity of the water is so low that a large percentage of the total head is lost by percolation through the banks of the ditch, and by evaporation. Sediment is deposited in ditches of this nature, which also tends to decrease the flow. On the other hand ditches where grades are 0.2 foot per one hundred feet and upwards are apt to be subject to serious damage by erosion where the soil is light.

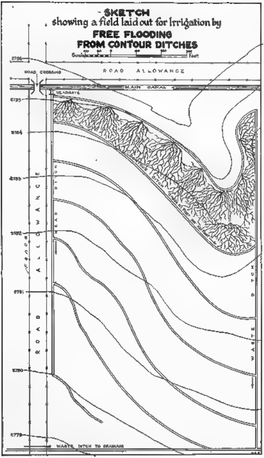
Proper Spacing of Ditches and Reasons Therefor. The distance between farm laterals will vary in accordance with the irrigation head available, the character and porosity of the soil, and the degree of smoothness of the ground surface. Laterals are often spread too far apart, resulting in uneven depth of application, over-irrigation of land near the ditch and under irrigation of the far edges of the land. On well graded land of gentle slope a good general rule to follow is to space the laterals one hundred feet apart where an irrigating head of about two and one-half cubic feet per second is available, one hundred and fifty feet apart where a head of three to four second-feet is available, and not over sixty feet apart where there is only one second-foot available.

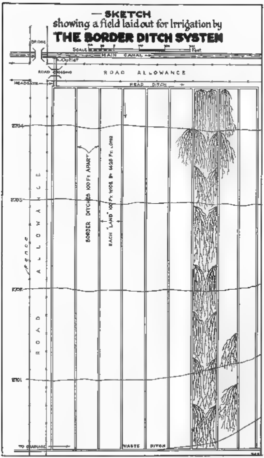
When applying the first irrigation, with an inadequate head of water, to a thoroughly dried out, dusty field, it is very discouraging to see the water spread only from one half to two-thirds of the way across the land. The water soaking into and filling the soil near the supply ditch to the saturation point, is laying the foundation for serious trouble later on from a rising water table, alkali, etc. It is much better to have the ditches close enough so that light irrigations of uniform depth may be quickly applied. On old alfalfa fields and well established grass meadows the distance given may be increased about fifty per cent. Where the soil is very sandy or gravelly, it will be necessary to decrease these distances, as the porosity of the soil and the slope of the land seem to warrant. The enhanced crop yields, obtained as the result of light frequent irrigations of uniform depth, more than compensate for the additional area of land taken up by the close spacing of ditches.

The Different Systems of Irrigation and their Application to Alberta Conditions

The Free Flooding Method, by Contour Ditches. This method is still in more general use than any other, particularly in new projects, as it requires less grading than either of the other systems, and can be profitably used on slopes which are too steep for other methods and where the general topography of the tract is rolling. In general principle it consists in having a main supply ditch running along the higher side of the farm, or possibly along some ridge or high land, and from this head ditch taking off laterals which shall closely follow the contour of the land across the fields. The spacing between ditches is more variable than with the other systems on account of the different slopes encountered across the field. On steep slopes the laterals may approach as near as fifty feet apart, while, where the field gets flatter, they may be two or three hundred feet apart. This makes it difficult to apply water uniformly and is one objection to this method of irrigation; another is that the lands between ditches are irregular in shape, requiring more labour in harvesting the crop than in regularly shaped parcels.

The Border Ditch System.—In this method the ditches are run straight across the field, parallel to each other and from fifty to two hundred feet apart, the distance depending upon conditions described under the heading "Proper Spacing of Ditches and Reasons Therefor." The ditches are usually run down the slope of the land but may be run on the bias across the slope where the fall of the land might cause excessive velocity of flow. Where the topography of the land is uniform this method is to be preferred to any of the free flooding methods, as with it the field is divided into rectangular lands. These lands are much more easily farmed than the irregular areas of the contour system. It is especially desirable to have the more important field crops, such as alfalfa and hay, watered by a rectangular system of ditches. In grain fields, however, where the ditches are ploughed in before each harvest, the


SKETCH
showing a field laid out for Irrigation by
FREE FLOODING
FROM CONTOUR DITCHES
Feet
ROAD ALLOWANCE
ROAD CROSSING
MAIN CANAL
HEADGATE
CONTOUR DITCH
HEAD DITCH
ROAD ALLOWANCE
WASTE DITCH
WASTE DITCH TO DRAINAGE


— SKETCH
showing a field laid out for Irrigation by
THE BORDER DITCH SYSTEM
BRIDGE
SCALE
Feet.
MAIN CANAL
Outlet
ROAD CROSSING
ROAD ALLOWANCE
HEADGATE
HEAD DITCH
BORDER DITCHES 100 FT. APART
EACH "LAND" 100 FT. WIDE BY 1428 FT. LONG
ROAD ALLOWANCE
FENCE
2704
2703
2702
2701
TO DRAINAGE
WASTE DITCH

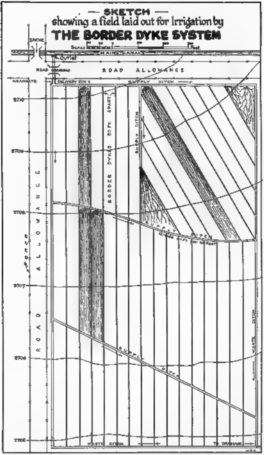
necessity of having rectangular lands is not so imperative With the border ditch system, a more even application of water may be made than with either the contour or the border dyke systems The water may be turned into the "land" from the border ditch on each side, allowed to run until the land for the length of a hundred feet or so has been covered, then by shifting the canvas dams, it may be turned into the land again farther down—the operation being repeated until the land has been completely covered This obviates the necessity of allowing the water to run for any excessive length of time over any part of the land, such as is the practice when, under the border dyke system, the water is turned into the land at the head of a border four or five hundred feet long, and allowed to run there until it has spread the entire length of the border.

When conveying the water along the edge of the field from the head of one contour ditch, to the head of another, or between one border ditch and another, excessive slopes will frequently be encountered, but as the length of run is short the erosion will not be great enough to cause serious damage

The Border Dyke System.—This system is especially well adapted to the irrigation of permanent pastures and alfalfa fields It is more costly to install than the other systems described and for that reason should not be used for grain fields which have to be ploughed up each year as the ploughing destroys the small border dykes After alfalfa fields have been established on land prepared for this system of irrigation, very little work is necessary to properly irrigate. It lends itself very well to the use of a large head of water, and permits of the entire field being cut as one unit, as the harvesting machinery easily rides over the low broad dykes, thus materially reducing harvesting costs

Use of Ridger for making Borders.—(Photo by Don H Bark.)

Essentially, this system consists of the division of the field into long, narrow strips of land by means of low, flat levees which usually extend in the direction of the greatest slope and confine the water to a single strip of land. The bed of each strip should be carefully graded to a uniform slope transversely so that when a sheet of water spreads down the land it will not tend to flow to either edge of the strip. The small levees are made either with a Fresno scraper or an implement termed a "Ridger" (See illustration). The levees are first marked out by lines of stakes,


— SKETCH —
showing a field laid out for Irrigation by
THE BORDER DYKE SYSTEM
Scale
Feet
BRIDGE
MAIN CANAL
Outlet
ROAD CROSSING
ROAD ALLOWANCE
HEADGATE
SUPPLY DITCH
2710
2709
2708
2707
2706
2705
BORDER DYKES 50 FT. APART
SUPPLY DITCH
ROAD ALLOWANCE
SUPPLY DITCH
SUPPLY DITCH
WASTE DITCH
WASTE DITCH
TO DRAINAGE

them about two furrows each way are ploughed and thrown together to make ridges. These ridges are then gone over with the "Ridger" which gathers an additional amount of earth from an area six to eight feet wide on each side of the ploughing and heaps it up behind, making the levees or ridges. These levees are then gone over lengthwise with a harrow to smooth them down so that when compacted, and after settling, they will be about six inches high, five feet wide and rounded over. Levees are spaced from thirty to sixty feet apart, usually about forty feet on average

Large Machine Ridger made by the Canada Land & Irrigation Company

smooth land, but may be spaced closer where the slope of the land is greater or the soil very porous. These borders may vary in length from five hundred to one thousand feet depending upon the porosity of the soil, the slope of the land and the irrigation head available. With a head of about three second-feet they should be between four hundred and six hundred feet long for average soil. As the available irrigation head is increased the length of the borders may also be increased. In sandy soil the length of the borders must necessarily be much less. Head ditches are run across the fields to supply the borders.

The levees may also be made with Fresno scrapers, sufficient earth to make the levees being obtained by skimming the surface of the borders with the Fresno. The scraper teams begin at the head ditch and work down, crossing and recrossing the border at right angles to the levee, the scraper being dumped as it passes the line marked out for the levee. After the levees have been made by this method, the border or "land" should be thoroughly floated and levelled transversely.

Where sufficient water is available, say ten to twelve second-feet, one man can irrigate up to thirty acres in a twelve hour shift by this method. Permanent head gates should be constructed capable of turning large heads of water into each border.

The Furrow or Corrugation Method. The corrugation system is used almost exclusively in the older irrigation districts of southern Idaho, U.S.A., where the soil is a fine clay loam which runs together, puddles when wet and bakes and cracks when dry. Flooding this type of soil by any of the free flooding methods tends to puddle the top layer of soil which becomes quite hard when the moisture has evaporated. This puddling and baking process injures alfalfa, and it is with the object of preventing this that the corrugation system has been used so extensively

When fields are irrigated by this method, small streams of water are allowed to run down the corrugations for several hours, soaking the subsoil and spreading laterally by capillarity, meanwhile leaving the surface of the soil comparatively dry.

Irrigation by the corrugation method is especially desirable when a light, easily washable soil has been seeded to alfalfa or clover, as surface flooding would wash out many of the seeds. By running water down the furrows, the soil between them is soaked by capillarity and the tiny seeds are not disturbed. The length of the furrows should vary with the soil type and the slope of the land, from six hundred feet in medium to two hundred and fifty feet in very sandy soils.

Home-Made Corrugator.

The corrugations are usually made with an implement called a corrugator (see illustration), and are spaced about thirty-two inches apart, although this distance may be decreased to sixteen inches in heavy impervious soils. These corrugations, which are supplied with water from head ditches spaced from three hundred to five hundred feet apart, are laid out across the field as nearly parallel as possible on a grade of from two to six inches per one hundred feet, in the direction of the greatest slope of the land. Where this slope exceeds the allowable grade for a soil, the corrugations must be laid out on a bias across the slope. Checks, usually in the form of small gates, are placed in the head ditches. These gates may be either wholly or partially closed to maintain the water at a desirable height in the ditches. The water is let out of the ditches into the corrugations through small pipes sixteen to twenty-four inches long, made of four laths nailed together, which extend through the ditch bank. These pipes should be placed in the ditches while they are full of water so that the inlet of each pipe may be at the same distance, about three inches, below the surface of the water in the ditches, thus ensuring an equal quantity of water being discharged through each pipe. The flow of each pipe may be divided amongst several corrugations. The disadvantages of the corrugation system are: first, that the water is rarely distributed evenly; and, second, that there is always a great loss by deep percolation, especially where the corrugations have too great a length between head ditches.

Construction of Farm Laterals.—After the location of a farm lateral has been determined and marked with a line of stakes, the lateral may be constructed with either a walking plough and "V" ditcher or with a ditching grader.

"V" Ditcher in Operation.

Machine Ditcher

Laterals are constructed with the plough and "V" ditcher as follows A furrow, six inches deep, is opened out along the line of stakes. The team is then turned and driven back over the furrow just ploughed. The plough is placed in the bottom of the first furrow ploughed, and so adjusted, by means of the clevis, that it will turn out a second furrow, six inches deep, in the same line but immediately underneath the first

furrow This method makes a rough ditch, approximately one foot deep and two feet wide, with the earth ploughed out evenly on both sides. The ditch is completed by hitching a heavy team to the "V" ditcher and pulling it through the rough ditch about twice on each side to smooth down the banks and throw out the loose earth. A

Martin Ditcher

Large Ditching Plough.

four-horse evener is used, with a horse hooked at either end and the inside reins lengthened out about three feet, so that each horse may walk on the outside of the ditch bank. One man stands on the point of the "V" and drives the team. A second man walks outside the ditch and by means of a long handle fastened to and in line

with the smoothing blade of the "V," keeps it at a constant angle. This method makes a smooth "V" shaped ditch with a carrying capacity of from one to two cubic feet per second. To make a larger ditch with the wooden "V," such as would be used for a flow of from two to four second-feet of water, it is necessary to hook the team to the plough by means of a log-chain and ride the plough, taking an additional furrow or so from the bottom of the ditch as constructed above and running the ditcher through once or twice after the second ploughing. Where a steel "V" ditcher is used it will usually cut the ditch deep enough by making several rounds without any more than the first ploughing.

The "Martin ditcher" is made on the same principle as the ordinary "V." It is of steel construction throughout, and being much heavier than the wooden "V" requires four horses for its operation. It cuts much deeper than the wooden implement and makes a better ditch. Very good ditches have been made by hooking a Martin ditcher behind a Fordson tractor.

Diverting water with a canvas dam.

The points to remember for making straight ditches with good water-tight banks are:—

(1) The two plough furrows must be made in the same vertical plane, *not* side by side.
(2) The angle of the cutting blade of the ditcher must be regulated by a man walking outside the ditch. It is not possible to make continuous, uniformly sloping banks by endeavouring to control the ditcher while riding the rear end.
(3) The ditcher should be pulled through the ditch at least twice each way; this fills up the small holes in the banks and makes the banks higher and more substantial.
(4) The sides of the ditch should have a slope of about forty-five degrees.

Weak places will frequently be found at points where the ditch crosses "burn-outs" or suddenly changes direction. These places should be reinforced until they are as strong as the remainder of the ditch. Very deep depressions or coulees will necessitate work with teams and scrapers, and in extreme cases the construction of a flume.

Applying the Irrigations.—It is well to study irrigation problems in advance. A schedule should be drawn up showing how many irrigations each field is to receive, the dates upon which each is to be irrigated, and the depth of water to be applied per irrigation. This plan will enable the season's irrigation work to be seen as a whole. Knowing how much water to expect, and the labour available, the work can be arranged so as to economically irrigate the different crops. This is much more satisfactory than dealing with the problem in a haphazard manner as the necessity arises and without any pre-arranged plan.

Use of Canvas Dam.

The Use of the Canvas Dam.—The canvas dam is absolutely indispensable. The irrigator should have several. These are usually made from twelve-ounce to twenty-ounce canvas, and should be about four feet wide and six feet long, but may be larger

for larger ditches. The six-foot side is fastened to a 2- by 2-inch scantling either by nails through a lath, or by folding the canvas over the pole and sewing it together, thus making it possible to withdraw the pole and fold the canvas when not in use.

This dam is used to divert water from the various laterals to the land. It should be put in place before the water reaches the point of diversion and should be laid in the ditch with the canvas extending up stream and the pole spanning the ditch and resting on each bank. Some earth should be thrown on the canvas to hold it in place. The ditch bank should then be opened at one or more points as desired, to distribute the water on the land.

In cases where the border ditches are one hundred feet apart, the water should run on the land until it has covered approximately two hundred feet down the border, this distance varying according to soil, slope, etc. Meanwhile a second dam should be set farther down the ditch. When the water has spread down the land to a point opposite the second dam the first dam should be removed, thus allowing the water to run down the ditch and be diverted by the second dam. This process is repeated down the length of the border until the entire land has been watered.

Points to be Noted in Irrigation—

(1) Never attempt to irrigate too great a length of land from one "set", it will over-irrigate the land near the dam and cause too great a loss of water by deep percolation.

(2) After a dam has been removed and the water allowed to run down to the next set, all openings in the ditch banks used to allow the water to run on the land from previous sets should be closed. Failure to do this causes loss of irrigating head and over-irrigation.

(3) Care should be taken that all dry spots are reached and that no area capable of irrigation is left unwatered in the vicinity of the set. Small ditches should be made with the shovel to lead the water to such points as are not readily flooded by the flow diverted by the dam. The damage caused by these small ditches will be negligible when compared with the increased yields due to the thorough and uniform distribution of the water.

(4) It is always best to start at the upper end of a "land" and irrigate towards the lower end.

Applying the Correct Depth. In order to apply the correct depth per irrigation and thus effect the greatest economy in the use of water, the area of land to be irrigated must first be ascertained.

The area in acres of any rectangular piece of land may be closely approximated by multiplying the number of paces (yards) in length by the number of paces in width and dividing by 4,840. Where the land is one hundred feet wide between parallel ditches, a length of one hundred and forty five paces equals one acre.

The irrigating head, or quantity of water in cubic feet per second, flowing down the ditch, may be measured by weirs, orifices, or in the ditch near the point of diversion on to the land. The most accurate measurement can be secured with weirs, but a very close approximation of the discharge can be obtained by multiplying the area of the wetted cross-section of the ditch by the velocity of the flowing water in feet per second. For example, assume a field of ten acres, divided into "lands" by ditches one hundred feet or thirty three and one-third paces apart. These "lands" on being paced out measure two hundred and ninety-one paces in length. Then $\frac{291 \text{ paces by } 33\frac{1}{3} \text{ paces}}{4840} = 2$ acres. The irrigating head is then determined by any of the methods mentioned above, to be, say three cubic feet per second, usually described as "three second-feet." One second-foot will deliver one acre-inch per hour, or in twenty-four hours will cover an acre to a depth of twenty-four inches. Therefore three second-feet will deliver three acre-inches per hour. Assume that the crop grown is grain, and that it has been decided to apply to it a six-inch irriga-

tion. This means a depth of six inches of water on each acre or a total depth of twelve inches for each "land." The irrigating head will deliver three acre-inches per hour, hence it should take $\frac{12}{3}$ or four hours to irrigate the two acres, or two hours per acre. Knowing that each land should be irrigated in four hours, or two hundred and forty minutes, it follows that it will be necessary to cover a length of fifty paces about every forty-one minutes. The operation should, therefore, be regulated accordingly. Where it takes a longer time to cover the land than has been calculated, it will be apparent that more than the correct depth is being applied.

It will be found in actual practice that many factors, such as condition of soil, roughness of land, stage of crop growth, and method of seeding, will have a marked influence on the degree of exactness with which the irrigation programme can be carried out. Nevertheless, the man who knows just how much water is wanted on each field, and exactly how it can be applied most economically, will get through the irrigation programme most expeditiously and the land will be left in better condition for crops than where the water is allowed to run until the soil *has the appearance* of having received enough.

It has been found that a single disc press drill is a great aid in distributing irrigation water evenly. This may sound unreasonable but is nevertheless true. This type of press drill leaves the seed bed covered with small, well defined corrugations about two inches deep, a depression where the press wheel has compacted the soil over the seed, and a ridge of earth thrown up between the seed rows by the single disc. When the seeding is done in the direction of the greatest slope of the land, these small corrugations act as tiny ditches in distributing the water. An experiment was carried out at the Brooks Experimental Station, where (*a*) peas were sown three inches deep with the press drill, the rows running down the slope, and (*b*) where the peas were sown with the ordinary drill and harrowed afterwards. Much better yields were obtained in (*a*) than in (*b*). It was found that the harrowing left the land too smooth. The water spread over the surface too fast, and instead of running down the land, as it did where the press drill was used, ran too much across the land and wasted along the farther ditch edge.

Night Runs.—In the irrigation of large fields it is frequently necessary to let the water take care of itself especially through the night. At best, this is a wasteful and unsatisfactory method of irrigating, but as it is frequently impossible or inadvisable to shut the water off when the irrigator quits for the night, a few hints as to how this phase of the situation can be handled may not be amiss. Experienced irrigators will select for the night run those lands which have the most uniform topography, where there will be the smallest loss from surface run-off. The water should be turned on the land in several places and dams put in the lower ditches so as to catch the overflow from the irrigated lands and re-divert this waste to irrigate other lands. When the irrigator returns next morning and inspects the fields, he will probably find numerous spots which the water has missed. These spots should be watered before moving to other lands.

SECTION 2

IRRIGATION INVESTIGATIONS

Outline of Work.—It is a disconcerting fact that even if the maximum facilities for storage are provided and the most careful use is made of the available water, there will not be sufficient to irrigate more than 5,000,000 acres, or about ten per cent of the land requiring irrigation in Alberta and Saskatchewan. To provide

reservoirs for this limited supply and to so conserve and use it at all times that the greatest benefit may be derived by the greatest number, are tasks that to-day challenge the West.

In the early days of irrigation in Canada the streams carried a surplus of water, and irrigators, without thought of scarcity, applied it to their lands with lavish prodigality. Credit is due to the framers of the Irrigation Act, who, learning from the unfortunate experiences of the Western States and looking to the future when every drop of water would be needed, provided in the Act that a limit should be placed upon the quantity of water that might be appropriated for use per irrigable acre. Two acre-feet each irrigation season, or sufficient to cover each acre to a depth of two feet, measured at the point or points of delivery to any farm unit, was considered to be sufficient for the average need of crops in Western Canada and this quantity was established as the "legal duty of water." In recent years it became apparent that even this was an excessive quantity to apply to most crops and the duty was therefore increased to one and one-half acre-feet per acre, i.e., the duty or work that a unit quantity of water is required to do was increased.

Theoretically, the duty of water is the volume of water that is required to mature a crop on an acre of land. Under similar conditions it remains fairly constant for the same crop, but, as might be expected, it varies widely for different crops, soils and climates. The significance of this fact can only be appreciated by those who know how excessively irrigation water is applied to-day and what an enormous saving of water and increase of production would result if every irrigator could know approximately how much water he should use for each particular crop and soil, and would apply it according to scientific rather than haphazard methods. Such an ideal condition can of course never be fully attained but it is one toward which every irrigator should strive.

As the Minister of the Interior is responsible for the administration of the surface water supply of Alberta and Saskatchewan and particularly as he must define the duty of water, (or the water requirements of crops) according to locality and soil, duty of water investigations were commenced several years ago, from the results of which it is now possible to draw conclusions of great value and interest. These investigations were undertaken for the purpose of securing reliable data relative to:—

(1) The amount of water required to produce the maximum yield of specific crops when grown under varying conditions of soil fertility, soil texture and climate.

(2) The proper depth of water to apply per irrigation for different soil types and for different crops.

(3) The relationship between the "irrigating head" and the distance between the distributing ditches.

(4) The seasonal water requirements of various crops, or the time when irrigation water should be applied.

(5) The amount of water supplied to, wasted from, and used on the farms of a typical local irrigation project.

The first experiments were conducted in 1913 on small plots set aside for the purpose by farmers in the Coaldale district.

In 1914 a tract of some forty acres was secured at Strathmore, where duty of water investigations were carried on in co-operation with the Department of Natural Resources of the Canadian Pacific Railway Company. This station was operated until 1917, when it was abandoned owing to the rise of the ground water level so near the surface as to materially influence the yields of the various plots by sub-irrigation, thus rendering unreliable any data obtained from the application of different quantities of water.

In the year 1914 a tract of some twenty-three acres was secured from the Canada Land and Irrigation Company at Ronalane, where investigations were carried on co-operatively with the company until 1921, when the station was abandoned in favour of a more desirable location on the company's farm near Vauxhall.

During 1915 and 1916, a programme of irrigation demonstration work was conducted in the Strathmore and Gleichen districts, irrigation specialists, working in co-operation with the farmers, demonstrated irrigation methods and advised the farmers regarding the amount of water needed by crops and the most economical depth to apply per irrigation.

In 1917 the Dominion Duty of Water Experiment Station was established on a forty-acre tract of land leased from the Canadian Pacific Railway Company, situated one and one-half miles west of the town of Brooks. The most reliable and complete experimental data have been secured from this station because the experiments were much more carefully planned and carried out than was possible at either Strathmore or Ronalane.

Thus, since 1913, the Reclamation Service has been gathering at Coaldale, Strathmore, Ronalane and Brooks information regarding the duty of water for a variety of crops under climatic and soil conditions which are typical of different parts of southern Alberta.

The definite knowledge which has thus been obtained of the proper amounts of water to apply to crops clearly indicates that the past and present practice of applying water lavishly does not pay. It wastes water, tends to produce alkaline and water-logged soil and in the end results in greatly reduced yields. The problem now is to convince irrigators of these facts, so that the quantity of water used per acre may be reduced and the water thus saved may be made available for distribution to others. The recent increase of the legal duty of water from two acre-feet to one and one-half acre-feet per acre has had the effect of increasing the available supply nearly thirty-three per cent and further economy in the administration of water will result when it becomes possible to define for each large irrigation project the duty of water that will best satisfy its requirements.

Duty of Water.—The factors which directly influence the water requirements of any crop are: the physical properties of the soil and subsoil, the fertility of the soil, the size of the irrigating head, the depth applied per irrigation, the preparation of the land, and the climatic conditions.

Physical Properties of the Soil and Subsoil.—Soil texture has a greater influence on the duty of water than any other one factor. In the more porous soils, such as light sands or gravels, serious losses of water occur by deep percolation. When an attempt is made to run a relatively small head of water across a "land" where the soil is very porous, the downward movement of the water is so rapid in comparison with its lateral movement over the surface, that either the subsoil becomes saturated before the surface area to be watered has been fully covered, or the downward movement of water becomes so extensive as to stop the lateral or surface movement entirely.

In the heavy or less porous soils the extent of the downward movement of the water, in comparison with its movement over the surface, is much less than in the light soils. Consequently a heavy type of soil will permit of the ditches being spaced much farther apart than when using the same irrigating head on a more porous soil.

Soil moisture investigations show that the light sandy soil at the Strathmore station under free sub-drainage conditions, holds a maximum amount of but one to two inches of available water per foot in depth, while the heavier clay loam soil at the Brooks station, under the same conditions, holds two and one-half to three and one-half inches.

Assuming that the irrigating head, length of run and width of land between ditches are similar, and taking into consideration the water-holding capacity and rate of percolation peculiar to each soil type, it would be found that by the time the

heavier soil had been filled to capacity and was holding from ten to fourteen inches of water in the four-foot soil column, the lighter soil would not only have reached its maximum holding capacity of from four to eight inches, but would actually have lost some six inches of water by percolation below the four foot depth.

Moisture moves through the soil by capillarity in all directions, as influenced by the combined forces of gravity and surface tension of liquids. This movement is usually upward, or towards that point where moisture is being drawn from the soil either by the roots of plants or by evaporation at the surface. The rate at which water moves through the soil by capillarity is never very rapid when compared with the movement of the greater volume of water downward by gravity. The rate of capillary movement is influenced by the arrangement and size of the soil particles—the coarser the soil particles the shorter will be the distance the moisture can rise—hence, a coarse, sandy soil not only has less water holding capacity than a heavy soil but returns a smaller portion of its water to the surface by capillarity.

Crops grown on the sandy soil of the Strathmore station were observed to be "burning up" for lack of sufficient moisture even when the water table stood at a depth of only six feet below the surface.

To irrigate very porous soils with the least possible percolation loss, requires that the distance between distributary ditches and the size of the irrigating head be so proportioned as to permit of the application of light irrigations. To do this it is necessary that the irrigation head be larger in comparison with the distance between ditches than would be the practice on the heavier soils.

Fertility. It is a proved fact that the more fertile the soil the less water will be required to produce a given yield; therefore the duty of water for any specified yield per acre will vary as the soil is rich or poor in available plant food.

The effect of fertility upon the water requirements of crops was very convincingly demonstrated by an experiment carried out at the Brooks station during 1920. Banner oats were grown under four different conditions of soil fertility. A total depth of 1.75 feet of water produced yields ranging from one hundred and thirty two bushels per acre where the preceding crop was clover, down to eighty two bushels per acre where three other grain crops preceded the oat crop.

Size of Irrigating Head and Depth Applied per Irrigation. The average irrigating head used in the Coaldale district, as calculated from the results of water measurements made on some twenty farms in this district during the past nine years, is 2.37 cubic feet per second. As a general rule very few irrigators care to work with a smaller irrigating head than this, the majority preferring a second foot or so additional. A head of from two to three cubic feet per second is about all that one irrigator can handle to advantage on most fields where very little leveling work has been done and where the water is applied by the free flooding system. Where the land has been leveled and laid out in either the border dyke or border ditch system, much larger heads can be used.

Irrigation experiments conducted at Brooks, Ronalane and Coaldale with cereals, have demonstrated that only in cases of extreme soil water exhaustion is it practical or economical to apply irrigations in excess of six inches per application. The best results have been obtained where the water was applied in four and six inch irrigations. Twelve inches of water have usually produced better yields of grain when applied in three irrigations of four inches each than when applied in two irrigations of six inches each. In order to apply light irrigations, comparatively large irrigation heads should be used, with ditches relatively close together so that the water may be flooded across the land quickly. A common practice in the Coaldale district is to apply to grain fields two irrigations, each of about nine inches depth, during the growing season. This is not an economical practice; it tends not only to water-log the soil but also to leach out the available plant food. Much larger yields could be obtained if the eighteen inches of water were applied in three irrigations instead of in two.

As explained previously, it is only under the very driest conditions that more than a four-, or at best a six-inch irrigation, can be entirely retained in the upper portion of soil, penetrated by the roots of the plant, or the root zone.

Light, frequent irrigations will do much to lower the total amount which must be applied to crops to produce maximum yields and the use of large irrigating heads, in comparison with the width of lands across which the water is to be spread, will facilitate the application of these light irrigations.

Preparation of the Land.—Where the land has been well levelled it is comparatively easy to apply quickly an irrigation of uniform depth to all parts of the field with little surface or percolation loss. Where attempts are made to irrigate rough, rolling land that has not been levelled a great loss of water occurs, the high areas receiving little, if any water, the low areas receiving an excessive amount, hence, losing water by deep percolation. Water is also lost down the surface gullies and depressions of the land.

Time of Irrigation.—To determine just when crops need water and when to apply it so that they will not suffer from drouth, nor be injured by too frequent or too heavy applications, requires knowledge that can only be gained by experience and a close observation of various crops under irrigation.

It is difficult to determine just when the development of a crop is arrested by a deficiency of moisture in the soil. This point can be more definitely decided by an examination of the soil than by the appearance of the plant, as the plant does not show evidence of a check in its growth until some days after it has occurred. Usually it is then too late to prevent serious loss, as the crop rarely recovers from such check and never reaches the development it would have attained if it had been irrigated at the proper time.

Plants will usually indicate by a change in colour or by their general appearance when they need water and also when they have been over-irrigated. Most field crops turn a darker green when in need of water and the leaves and stems show a tendency to droop or curl. The lower leaves assume a pale yellow hue. A crisp or dead appearance in the lower leaves is one of the best indications that a plant is suffering from lack of water. Grain that has suffered from drouth may mature, but the straw will be short and the kernels shrunken. When field crops have been over-irrigated the colour of the foliage becomes a yellowish green and the plants have a sickly appearance.

The amount of moisture in the soil may be roughly determined by examining a handful of earth taken from about one foot below the surface of the ground. If it clings together when moulded into a ball and shows the imprint of the fingers, there is still sufficient moisture present. If the earth falls apart when the hand is opened, irrigation is needed.

Irrigation investigations carried on at the Brooks station during the past four years produced results which indicated that the total depth of water required to produce the maximum yields of wheat, oats and barley was between 1.62 and 2.00 feet, of which approximately 0.35 foot was received as precipitation, leaving between 1.27 and 1.65 feet to be applied by irrigation.

The daily water requirement of crops varies considerably throughout the growing season, being influenced by climatic conditions and transpiration. Under like conditions of precipitation, wind movement and stage of growth of crop, the water requirements, as influenced by temperature, would be greatest during the hottest summer months, usually June and July. With like conditions of precipitation, temperature, wind movement and soil water content, the water requirements as influenced directly by the transpiration of the plants will vary with the stage of growth and leaf surface. Transpiration, although quite low during the spring months, increases with the growth of the plant until sometime during June or July when it reaches its maximum. A study of the rate of growth of grain crops carried out under ideal conditions during the summer of 1915 at Gleichen, showed that a total growth of 43 inches attained during the season, ten per cent was attained during

May, twenty-two per cent during June, sixty-seven per cent during July and one per cent during August. The greatest increase in height and leaf surface was, therefore, attained during the hottest month—July. Soil moisture investigations made in connection with this study showed the highest daily water use to be in July.

Experiments carried out at the Brooks station during the past four years show that of the total amount of water which it has been found necessary to apply to grain by irrigation (say, for example, twenty inches) approximately one inch was needed in April, two inches in May, nine inches in June, seven inches in July and one inch in August.

	April	May	June	July	August
Percentage of total height attained		10	22	67	1
Percentage of total irrigation water used	5	10	45	35	5

The preceding table shows that the water requirements for grain are greatest during June, the rate of growth greatest during July. Therefore, the needs of the crop must be anticipated, water must be stored in the soil to provide for an unchecked growth.

Maximum crop yields are obtained under conditions where the best, or optimum, soil moisture content is maintained throughout the growing season, the crop at no time having any difficulty in obtaining sufficient water for its needs. To maintain this optimum moisture content, it is necessary to apply the irrigations more frequently during that period of the growing season in which the daily water consumption is greatest—through June and July.

Throughout southern Alberta there is usually sufficient water in the soil, when supplemented by spring rains, to supply the few inches needed during April and May, the bulk of the irrigation water must then be applied during June and July. The amount of water left in the soil after the last July irrigation is usually sufficient for the needs of the grain crop during August.

The maximum yields of grain at the Brooks station during the past four years, in which the precipitation during the growing season averaged approximately five inches, have been produced by applying water according to the following schedules.

Schedule (A), twenty inches of water applied in five irrigations of four inches depth each, the first irrigation being applied about June, followed by four irrigations at intervals of fifteen days.

Schedule (B), eighteen inches of water applied in three irrigations of six inches depth each, the first irrigation being applied about June, followed by two irrigations at intervals of twenty-five days.

Although requiring a little more work than with Schedule (B), water applied according to Schedule (A) has always produced larger yields of grain. This is due to the fact that the four-inch irrigations come more frequently than the six-inch and less water is lost by percolation.

It will be found economical to plan an irrigation schedule for each field and then so arrange the ditches, labour, etc., as to expeditiously carry out the schedule. When the rainfall between the scheduled dates of irrigations equals in amount one irrigation, an irrigation may be omitted. On the other hand, if in waiting for rain irrigation is delayed until the moisture content has been reduced to the point where the crop is suffering, it is often too late to water the field before serious damage occurs. This is especially true where large areas are farmed. It is much safer to anticipate irrigation needs.

Fall irrigation is always good crop insurance. The water stored in the soil in the fall will often provide for the needs of the next season's crop until well into June.

An adequate supply of moisture is required during that period in which the crop is making its most rapid growth, if this supply is not available the grain will not properly fill out. But of still greater importance is an adequate supply of moisture early in the season, if this is lacking, a poor stand of grain will result. It is in the early part of the season that the plant "takes stock" of the water it has available and arranges its life accordingly. A crop stunted from early drouth will never produce as much as if it had always enjoyed optimum growing conditions.

In many districts of southern Alberta during the past four years, it has been so dry in the spring that the soil at the time of seeding did not contain enough moisture to germinate the seed and no growth was made until the fields were irrigated. As it requires about one hundred and ten days for a crop of Marquis wheat, receiving all the water it needs, to mature, it can be readily understood that if this crop did not begin to grow until tardily irrigated, perhaps not until June, it would in going through its normal life span, mature nearly as much later as its germination had been delayed.

At the Brooks station, the heaviest watered grains matured well in season, providing they did not suffer from drouth at any time. Crops seeded April 20 were ripe by August 15.

Duty of Water Investigations at the Brooks Experiment Station

The soil at this station is generally fine and overlying coarser sand, with occasional patches of gumbo strata at depths varying from four to six feet. It is of such a character as would be expected to require comparatively large quantities of water. The land to be devoted to experimental work at this station was broken to a depth of three inches during June, 1917, and back-set to a depth of seven inches the following September. The land was then levelled by means of the Fresno and Float. All permanent ditches, weirs, roads and buildings were completed during 1917. The first seeding was done in the spring of 1918.

Plan No. 1 shows, in general, the layout of plots and, in detail, the location of the various rotations for the 1921 season.

Two-Way Plough.

General Cultural Methods Employed.—All lands were ploughed with a two-way plough. This type of plough has proved very satisfactory for use on irrigated fields as with it the furrows may be all thrown the same way, thus leaving no dead or back furrows to hinder irrigation.

After ploughing, which is usually done during October, the land is harrowed and floated and left ready for seeding the following spring.

The seeding is done with a press drill. The advantages of this type of drill are explained elsewhere in this bulletin. Directly after seeding, ditches are made with a walking plough and steel "V" ditcher.

The irrigations are applied according to schedule. The water is measured by means of Cippoletti weirs distributed over the farm at convenient places. Grain crops are harvested with a cut binder, forage crops with mower and rake.

Soil moisture tests are made in each plot at the time of seeding or beginning of growth in the spring and again at the time of harvest, in order that the amount of water in the soil at the beginning and end of the season's growth may be ascertained.

Threshing is done with a 24- by 32-inch separator.

Rotations.—In planning the work at this station it was decided to ascertain the water requirements of peas, wheat, oats, barley, flax, alfalfa, clovers and grasses.

As grains are grown under many conditions of soil fertility, it would serve no definite purpose to merely obtain duty of water data for general or average fertility conditions. It is essential that the water requirements of grain be ascertained, not only where grown under the most favourable, but also where grown under medium and poor fertility conditions, as the water required to produce a given yield per acre varies considerably with fertility. Further where data are desired covering a period of years on grain growing under a definite condition of soil fertility, it is evident that some provision must be made to ensure that this condition will be maintained each year with as nearly as possible the same potentiality for crop production. A rather comprehensive system of crop rotations was, therefore, planned to ensure the stability of the conditions as above described.

SCHEDULE FOR ROTATIONS

Rotation (A), alfalfa five years, potatoes, wheat, flax.

Rotation (B), Alsike clover four years, roots, oats, wheat, oats.

Rotation (C), grass three years, potatoes, barley, wheat.

Rotation (D), red clover two years, oats, barley

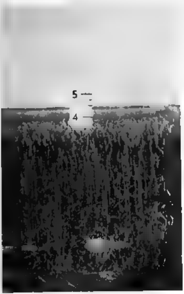
Rotation (E), peas, wheat, oats, barley

In each year data are obtained from four plots of alfalfa, differing in age from one to four years. The water requirements for alfalfa one year old will differ from the requirements for a four-year old crop, due to the percentage of stand and extent of root system.

Water Requirements of Wheat

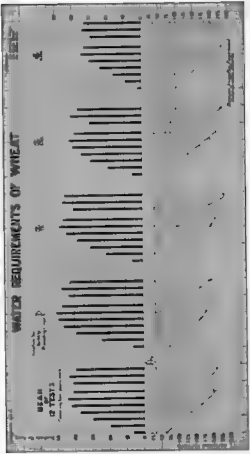
During the years 1918 to 1921 inclusive twelve experiments were made to determine the water requirements of Marquis wheat. The results of these experiments are shown on Diagram No. 1 by means of five graphs the first gives the mean result of all experiments under varying conditions of fertility and may be taken as representing the amount of water required to produce the given yields under average conditions, the next four graphs represent the results obtained when wheat was grown on soil where the fertility was (1) excellent, (2) good, (3) fair, and (4) poor. In graph (1), wheat immediately followed a legume, in (2), a crop of roots was grown

Marquis Wheat.



Five 4" Irrigations

Non-Irrigated



WATER REQUIREMENTS OF WHEAT
MEAN OF 12 TESTS

after the legume and immediately preceding the wheat crop; in (3), a root and a grain crop were grown between the legume and wheat crop, and in (4), two grain crops and one root crop were grown before the wheat, with no legume in the rotation.

The first column in each graph represents the yield in bushels per acre where no irrigation was applied the next six columns represent the yield obtained by the application of from four to twenty-four inches of water in four-inch irrigations, the last three columns represent the yield obtained by the application of from twelve to twenty-four inches of water in six-inch irrigations.

The number and size of irrigations applied to any plot are shown immediately under the rainfall and in line with the heavy column above, which represents the yield for that particular plot. The bottom of any irrigation column indicates the *total depth of water received* (irrigation plus precipitation) by that plot. *The total depth of water used in growing the crop* is shown by the dotted line and is that amount of water which has been used or lost from the soil, to a depth of six feet, by transpiration, evaporation, and percolation. It is determined by adding to the calculated water content of the soil at the time of seeding, the amounts received in the form of precipitation and irrigation and deducting from the sum of these amounts the amount of water remaining in the soil at the time of harvest.

The more important points shown by these graphs are,—

(a) The total depth of water received which produced the maximum yield per acre, where the crop was grown under four conditions of soil fertility.

(b) The crop producing powers of a given quantity of water under these conditions of fertility.

(c) The water used to grow the crop, together with the amount stored in and drawn from the soil.

(d) The relative value of four- and six-inch irrigations.

Total Depth Received.—The mean maximum yield from the twelve experiments —48.5 bushels per acre—was produced with a total depth of 2.02 feet of water, of which 1.67 feet were received in five 4-inch irrigations. In graphs (1), (2), (3), and (4), the maximum yields of 50, 47½, 41¾, and 34½ bushels per acre were produced with the same depth of water, 2.09 feet.

Crop Producing Powers.—Under optimum fertility conditions, as in graph (1), the total depth used to produce a yield of thirty-five bushels per acre was 1.05 feet, but in graph (4), under poor fertility conditions, it required a total depth of 2.90 feet to produce the same yield. The yield per acre produced with a total depth of 1.60 feet varied from forty-seven bushels in (1) to nineteen bushels in (4). These results emphasize the fact that it is necessary to maintain soil fertility in order to secure the greatest and most economical returns from the water applied.

Total Depth Used.—The water used to grow the crop on any plot is indicated by the position of the dotted line beneath that plot. For example in graph (1), the plot which received no irrigation, used, in addition to the rainfall received, about 0.35 foot of stored water from the soil. Each of the next four plots used some stored water, the amount in each case being represented by the vertical distance between the dotted line and the lower end of the irrigation column. Plot No. 6 neither stored nor drew from the soil water, having the same amount in the soil at harvest as it had at the time of seeding. The amount used was equivalent to the sum of the precipitation and the five 4-inch irrigations. Plot No. 7 did not use all of the water received, but stored approximately 0.20 foot. Storage of water is indicated wherever the dotted line lies above the lower end of the irrigation column, the vertical distance between the two points indicating the depth of water stored.

The following table gives the total depth of water used to produce a given yield of wheat per acre when grown under different fertility conditions, and irrigated by four-inch applications.

Bushels per acre	Optimum fertility as in graph (1)	Medium fertility as in graph (2)	Poor fertility as in graph (4)
10	0·85 foot	0·88 foot	1·08 feet
20	0·90 "	0·99 "	1·35 "
30	0·98 "	1·23 feet	2·02 "
40	1·18 feet	1·72 "	
50	1·32 "		

Relative Value of Depths per Irrigation.—The mean wheat graph shows that a greater depth of water is required to produce a given yield per acre when applied in six-inch irrigations than when applied in four-inch irrigations. A yield of thirty-six bushels per acre used a depth of 1·44 feet under four-inch applications and a depth of 1·56 feet under six-inch applications. A yield of forty-three bushels per acre used a depth of 1·80 feet under four-inch and a depth of 2·02 feet under six-inch irrigations. Therefore, a given amount of water, if applied to wheat in four-inch irrigations, will produce greater returns per acre-inch than if applied in six-inch irrigations.

SUMMARY

The total depth of water used which produced the maximum yield of wheat, taking a mean of twelve tests, was 1·90 feet when applied in four-inch irrigations and 2·00 feet when applied in six-inch irrigations. Under optimum fertility conditions, these figures were decreased approximately ten per cent and under poor conditions increased ten per cent.

WATER REQUIREMENTS OF OATS

The data obtained from thirteen experiments with Banner oats during the period 1919-21 are shown on diagram No. 2, which contains six graphs, the first showing average results for the thirteen experiments, the other five showing results obtained where the crop was grown under soil fertility conditions ranging from excellent, as in (1), where the preceding crop was a legume, to poor, as in (5), where three other grain crops had preceded the oat crop without a legume in the rotation.

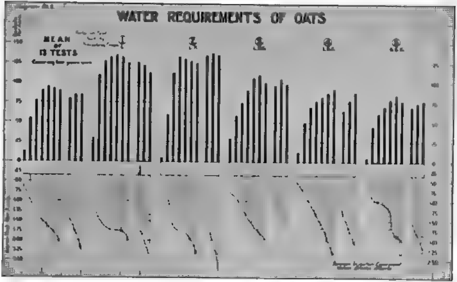
In general, the explanation given for diagram No. 1 as regards rainfall, irrigation column, dotted water used curve, etc., will apply to diagrams No. 2 to No. 5.

Total Depth Received.—The mean maximum yield for the thirteen experiments,—93 bushels per acre,—was produced under a depth of water of 1.68 feet, of which 1·33 feet were applied in four 4-inch irrigations. In graphs (1) to (5), the maximum yields, 135, 138, 108, 93 and 86 bushels per acre, were produced under depths of 1·68, 1·85, 2·02, 2·35, and 2·02 feet of water respectively.

Crop Producing Power.—Under optimum fertility conditions, as in (1), the depth used to produce a yield of 85 bushels per acre was 1·06 feet, but in graph (5), under poor fertility conditions, a depth of 1·85 feet was required to produce the same yield.

A depth used of 1·75 feet produced:—

136	bushels	per acre	in (1)
127	"	"	(2)
108	"	"	(3)
85	"	"	(4)
80	"	"	(5)


WATER REQUIREMENTS OF OATS
MEAN OF 13 TESTS

Using the same amount of water,—1 75 feet, the plot having excellent fertility produced 55 bushels per acre more than the plot having poor fertility.

Depth Used.—In considering graph (1), where the crop was grown under excellent fertility conditions it is observed that plots 3, 4, 5, and 6, which produced from 127 to 135 bushels per acre used approximately the same amount of water—1.75 feet. Plot No. 3 received 0.67 foot in irrigations and drew 0 66 foot of stored water from the soil. Plot No. 6 which produced the maximum yield, received 1 33 feet in irrigations but drew only 0 07 foot from the stored soil water

The following table gives the depth used to produce a given yield of oats when grown under different fertility conditions, using four-inch irrigations —

Bushels per acre	Excellent fertility as in graph (1)	Medium fertility as in graph (3)	Poor fertility as in graph (5)
40	0 72 foot	0·80 foot	0·88 foot
60	0·84 "	0·90 "	1 10 feet
80	0·96 "	1·14 feet	1·50 "
100	1 37 feet	1 57 "	
120	1 68 "		
135	1 75 "		

Irrigation Depth.—In the mean graph for oats it is shown that a greater depth of water is required to produce a given yield if applied in six-inch irrigations than if applied in four-inch irrigations. Eighty-three bushels, the average maximum yield of the thirteen oat experiments, used 1 80 feet with six-inch irrigations and but 1 35 feet with four-inch irrigations.

SUMMARY

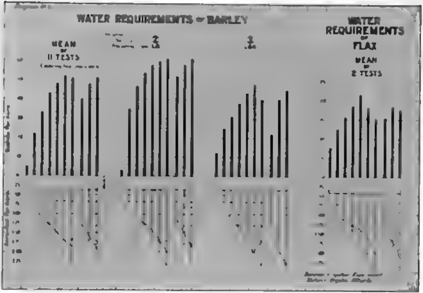
The depth of water used which produced the maximum yield of oats, taking a mean of thirteen tests, was 1 63 feet when water was applied in four-inch irrigations and 1 80 feet when applied in six-inch irrigations.

Water Requirements of Barley

The data obtained from eleven experiments with Ontario Agricultural College "No. 21" barley during the period 1919-21 is represented on diagram No. 3, which contains three graphs for this crop, the first showing average results for the eleven experiments, the other two showing results obtained where the crop was grown under soil fertility conditions ranging from good, as in (2), where preceding crops had been a legume then grain, to fair, as in (3), where the preceding crops had been a legume and two grain crops.

Depth Received.—The mean maximum yield for the eleven experiments, 52 bushels per acre, was produced under a depth of water of 2 00 feet, of which 1.07 feet were received in five 4-inch irrigations. In graphs (2) and (3), the maximum yields, 62 and 48 bushels per acre, were produced under depths of 2.35 and 2.00 feet respectively.

Crop Producing Power.—There is considerable difference in the fertility of the soil in the plot series represented by graphs (2) and (3). The clover preceding the series in graph (2) left the soil richer in plant food than the peas which preceded the series in graph (3)


WATER REQUIREMENTS OF BARLEY
MEAN OF 11 TESTS
WATER REQUIREMENTS OF FLAX
MEAN OF 2 TESTS

Yield in bushels per acre	Depth of Water Used to Grow the Crop		
	Fertility good as in (2)	Fertility fair as in (3)	Mean of 11 tests
10	0·55 foot	0·58 foot	0·65 foot
20	0·69 "	0·75 "	0·82 "
30	0·82 "	1·05 feet	1·03 feet
40	0·96 "	1 50 "	1 25 "
48	1·12 feet	2·00 "	1·48 "
50	1 16 "		1 56 "
52			1 67 "
60	1 67 "		

The depth producing the mean maximum yield, 1.67 feet, for the eleven experiments, produced 60 bushels per acre under good fertility conditions, as in (2), and but 43 bushels per acre under fair conditions, as in (3)

Depth Used.—By referring to diagram No. 3 it will be noted that in the first graph, which represents mean results, plots 1, 2, and 3 each drew upon the stored soil water to make up their deficiency Plot 4 neither stored nor drew from the soil water. Plots 5, 6, and 7 stored from two to six inches of the water received. Graph (3) shows no water stored until plot No. 7 is reached, where the stored water amounts to about eight inches. It is of interest to note that in the six-inch irrigation part of graph (3) no water is stored, while under better fertility conditions in graph (2), the plots irrigated with six-inch applications have stored about four inches of water each.

Irrigation Depth.—In the mean graph for barley it is shown that:—

A yield per acre of	When irrigated with 4″ applications used a depth of	When irrigated with 6″ applications used a depth of
40 bushels	1 25 feet	1·25 feet
48 "	1 48 "	1·65 "
52 "	1 60 "	1 96 "

Approximately twenty-two per cent more water was required to produce the maximum yields of these two series when applied in six-inch irrigations than when applied in four-inch irrigations.

SUMMARY

The depth of water used which produced the maximum yield of barley, taking a mean of eleven experiments, was 1.67 feet when water was applied in four-inch irrigations and 1 96 feet when applied in six inch irrigations.

WATER REQUIREMENTS OF FLAX

One graph only is shown for flax as this crop was grown each year under the same condition of fertility, that is, following wheat.

The mean maximum yield for two experiments, 21 5 bushels per acre, was produced under a depth of water of 1 75 feet, of which 1 33 feet were received in four 4-inch irrigations, the dotted line, however, shows that a depth of 1·34 feet only was used in producing this yield, the plot storing 0·41 foot of water.

This graph emphasizes the importance of the "dotted line" data, as gained by soil moisture studies made in connection with the irrigation treatment of each plot.

Without this data, conclusions would be drawn that a depth of 1·75 feet was necessary to produce the maximum yield of flax; with the dotted line data, however, the amount of water drawn from the soil or stored in the soil by each plot may be readily ascertained.

Yield in bushels per acre	Total Depth Used to Grow the Crop	
	With 4-inch irrigations	With 6-inch irrigations
7·5	0·72 foot	
10·0	0·85 "	
15·0	1·10 feet	1·60 feet
18·5	1·25 "	1·70 "
20·0	1·30 "	
21·5	1·34 "	

It required 5½ inches more water to produce a yield of 18·5 bushels per acre where applied in six-inch than where applied in four-inch irrigations. Flax, being a comparatively shallow-rooted crop, is best watered with the lighter irrigations.

The depths used which produced the maximum flax yield were 1·34 feet with four-inch and 1·70 feet with six-inch irrigations.

It will be noted that plot No. 5, which produced the maximum yield of flax, received a total depth of 1·75 feet, but used only 1·35 feet, storing 0·40 foot of water, the frequency of irrigation rather than the total depth applied being the main factor in influencing the yield.

Water Requirements of Canada Field Peas

Graph No. 1, of diagram No. 4, shows the mean results of four experiments with Prussian Blue peas. The maximum yield, 56 bushels per acre, was produced under a depth of water of 2·40 feet, of which 2·00 feet were received in irrigations. With four-inch irrigations a total depth of 2·55 feet was used to grow the crop, with six-inch irrigations a total depth of 2·25 feet. This indicates that the six-inch irrigation is better than the four-inch for peas. The following table gives the depth used to grow given yields of peas per acre.

Yield in bushels per acre	Total Depth Used to Grow the Crop	
	With 4-inch irrigations	With 6-inch irrigations
10	0·75 foot	...
20	0·95 "	..
30	1·10 feet	1·30 feet
40	1·50 "	1·50 "
50	2·05 "	1·70 "
[illegible]	2·45 "	2·25 "

Water Requirements of Alfalfa

Graph No. 2, of diagram No. 4, shows the mean results from four experiments with "Grimm" alfalfa. The maximum yield, 5·7 tons per acre, was produced under a total depth of water of 2·90 feet, of which 2·50 feet were received in the form of five 6-inch irrigations. Six and seven 6-inch irrigations produced a decrease in yield

The following table shows the depth of water used in producing a given tonnage of alfalfa.

Yield per acre	Total depth used	Yield per acre	Total depth used
1·00 ton. . . .	1·00 foot	5·00 tons. . . .	2·18 feet
2·00 tons . .	1·30 feet	5·50 "	2·31 "
3·00 "	1·68 "	5·70 "	2·62 "
4·00 "	1·80 "		

The depth of water used to grow the maximum yield was 2·62 feet in plot No. 8, although plot No. 7 produced but 0·15 ton less per acre and only used 2·81 feet. The former was irrigated with five 6-inch irrigations, the latter with six 4-inch irrigations.

Water Requirements of Alfalfa Grown for Seed

Graph No. 3, of diagram No. 4, shows results obtained with seed alfalfa. The crop series area was divided into five plots, plot No. 1 was non irrigated, the other four plots received from one to four irrigations of three inches depth.

Each plot was divided into three equal parts, on the first of which the alfalfa was sown in drills seven inches apart (D), on the second, in rows thirty-six inches apart (R), and on the third in hills thirty-six inches apart each way (H).

Where seeded in drills, the maximum yield, 7 bushels per acre, was obtained from plot No. 5, under a depth of water of 1·50 feet.

Where seeded in hills, the maximum yield, 6·2 bushels per acre, was obtained from plot No. 4 under a depth of water of 1·25 feet.

Where seeded in rows, the maximum yield, 5·8 bushels per acre, was obtained from plot No. 5, under a depth of water of 1·50 feet. The dotted curve showing the depth used to grow the crop agrees very closely with the depth received.

It will be noted that up to the point where two irrigations were applied, the maximum yield was produced by the hill seeding (H), as more water was applied the drill seeding (D) produced the greater yield.

This is a very important and interesting experiment and much more work has been planned along this line. The data here presented cover but three seasons' investigations, and while valuable as indicating the water requirements of seed alfalfa are not conclusive.

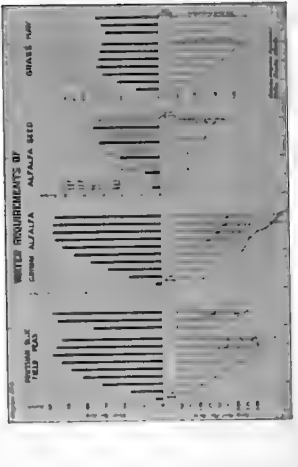
Water Requirements of Grasses

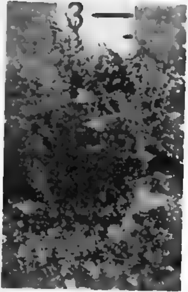
Brome grass, western rye grass, meadow fesque, meadow foxtail, timothy, and alsike clover were seeded in a mixture for hay.

Graph No. 4, of diagram No. 4, shows the results obtained. The maximum yield, 1·63 tons per acre, was produced under a depth of water of 1·35 feet. Beyond this depth the yield decreased. The four-inch irrigation has proved the better one for this crop.

The total depth used which produced this maximum yield was 1·50 feet, the crop having drawn 0·15 foot from the stored water of the soil in addition to using the 1·35 feet which it received as precipitation and irrigation.

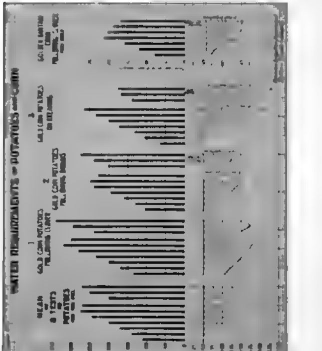
The yields of grass obtained at Brooks are quite low when compared with those obtained at Strathmore, the Brooks soil being much heavier than that of Strathmore and less adapted to the growing of grass crops.


WATER REQUIREMENTS OF
FIELD PEAS
GREEN ALFALFA
ALFALFA SEED
GRASS HAY



Water Requirements of Potatoes

The first four graphs of diagram No. 3 show the results obtained from eight experiments with Gold Coin potatoes. The first graph shows the mean results from the eight experiments; the next three graphs show results obtained where the crop was grown [illegible] after cereals, [illegible] after grass and [illegible] breaking.



1. [illegible] the maximum yield, [illegible] bushels per acre, was produced under a depth of water [illegible] feet, of which [illegible] foot was applied in four [illegible]-inch irrigations. In the same series, but where the water was applied in 2-inch irrigations, the maximum yield, [illegible] bushels per acre, was produced by the plot receiving a depth of 1·[illegible] feet, of which 0·[illegible] foot was received by irrigation.

The accompanying tables gives the depth used to produce given yields per acre where the crop followed clover.

Yield in bushels	Depth Used to Grow the Crop	
	When Water was applied in 2" irrigations	When Water was applied in 3" irrigations
150	1 16 feet	
200	1·35 "	1 35 feet
250	1·55 "	1·55 "
300	1 75 "	1·75 "
320	*1·80* "	1 70 "
340		*1·65* "

The depths used which produced maximum yields were for (1); 1 80 feet where water was applied in 2 inch and 1 65 where applied in 3 inch irrigations.

Water Requirements of Corn

Diagram No. 5 shows one graph giving the result of one experiment with Golden Bantam sweet corn.

The maximum yield, 21 5 tons per acre green weight, was produced by plot No. 4 which received a depth of 1 07 feet, of which 0·50 foot was received in three 2-inch irrigations.

This graph shows increasing yields up to the maximum and then decreasing yields as excessive depths of water are received. Two-inch irrigations have given more satisfactory results than irrigations of a greater depth.

The depth used to produce the maximum yield was 1·36 feet, the plot using 0 29 foot of water from storage in addition to what it received as rainfall and irrigation.

The production of marketable ears of sweet corn was in proportion to the yield of green crop. Plot No. 4 produced at the rate of 2,400 dozen ears per acre.

Summary of Investigations at the Brooks Station

The accompanying table gives the mean depth of water used which produced the maximum yields per acre, averaging the results from all the experiments made with each crop. For alfalfa, seed alfalfa, grasses and peas, the figures given represent the requirements of these crops when grown under optimum fertility conditions, for the other crops listed, the figures represent the water requirements of these crops when grown under average fertility conditions.

Crop	Number of experiments 1918 to 1921	Total depth used which produced the maximum yield per acre		Economical depth per irrigation in inches
		In feet	In inches	
Alfalfa	4	2·62	31	6
Peas	4	2·25	27	6
Wheat	12	1·90	23	4
Barley	11	1·67	20	4
Oats	13	1·63	19	4
Grasses	3	1 50	18	4
Alfalfa seed	3	1·48	18	3
Potatoes	5	1 65	20	3
Corn	1	1·36	16	2
Flax	2	1·34	16	4

Duty of Water Investigations at Ronalane, Alberta

Investigations were commenced in 1914 at Ronalane in co-operation with the Canada Land & Irrigation Company on a tract of forty acres owned by that company. This tract was chosen partly because of the exceptional facilities offered by the company for experimental work, partly because it is situated in the centre of an area of prospective irrigation development, but chiefly because of the fact that the soil and subsoil conditions are of a type relating to which it was very desirable that duty of water data should be obtained.

Depth of Soil.—The soil is somewhat lighter than at Brooks, washes easier and contains a higher percentage of fine sand. The soil of the main test plot area is only two to three feet deep and is underlain by a stratum of coarse gravel. In consequence, the water-holding capacity of this soil is relatively low as will be found by reference to the accompanying diagram and table. At Ronalane a given yield of grain per acre used much more water to grow the crop than at Brooks where the soil is deep. This is due principally to the greater percentage of each irrigation which is lost to the crop by percolation below the three-foot depth of soil.

Fertility.—All the plots at Ronalane except those growing alfalfa received frequent heavy applications of manure and the crops produced may therefore be considered as obtained under optimum conditions of soil fertility.

Depth of Irrigations.—Four-inch irrigations were used on the grain and pea crops and three-inch irrigations on the potato crops. The alfalfa plots were the only ones given six-inch irrigations, and were situated some distance north of the other plots on soil about six feet deep.

The accompanying diagram shows the average results obtained with six different crops, covering a period of four years, 1917 to 1921, inclusive.

Water Requirements

Canada Blue Peas.—The maximum yield of peas, 43·5 bushels per acre, was obtained with a depth of water of 2·37 feet, of which 2·00 feet were applied in six 4-inch irrigations. The depth used to produce the maximum yield was 2·37 feet. The field peas at Ronalane were subject to attacks of mildew, hence their low yields as compared with the yields obtained at Brooks.

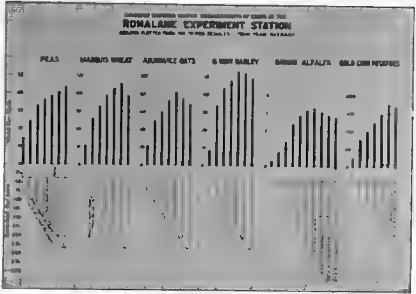
Marquis Wheat.—The maximum yield of wheat, 46 bushels per acre, was obtained with a depth of water of 2·02 feet, of which 1·67 feet (or 20 inches) were applied in five 4-inch irrigations. The depth used to produce the maximum yield was 2·20 feet.

Abundance Oats.—The maximum yield of oats, 81 bushels per acre, was obtained with a depth of water of 1·70 feet, of which 1·33 feet (16 inches) were applied in four 4-inch irrigations. The depth used to produce the maximum yield was 1·82 feet.

Bark's Barley.—The maximum yield of barley, 53 bushels per acre, was obtained with a depth of water of 1·70 feet, of which 1·33 feet (16 inches) were applied in four 4-inch irrigations. The depth used to produce the maximum yield was 1·75 feet.

Grimm Alfalfa.—The maximum yield of alfalfa, 3·25 tons per acre, was obtained with a depth of water of 2·40 feet, of which 2·00 feet were applied in six 4-inch irrigations. As the amount applied was increased beyond this point the yield diminished.

Gold Coin Potatoes.—The maximum yield of potatoes, 355 bushels per acre, was obtained with a depth of water of 1·65 feet, of which 1·25 feet were applied in five 3-inch irrigations.


RONALANE EXPERIMENT STATION
PEAS
MARQUIS WHEAT
ALFALFA

SUMMARY

The following table shows average depths of water for maximum yields at Ronalane:—

Crops	Depth received	Depth used	Yield per acre
Peas	2·37 feet	2·37 feet	43·50 bush.
Wheat	2·02 "	2·20 "	46·00
Oats	1·70 "	1·82 "	81·00 "
Barley	1·70 "	1·75 "	53·00 "
Alfalfa	2·40 "		3·25 tons
Potatoes	1·55 "		355·00 bush.

When comparing this table with the results obtained at Brooks, all Ronalane results are considered as coming under the heading of No. 1 fertility, due to the frequent applications of manure.

The principal factor responsible for so much water being required to produce the maximum yield per acre at Ronalane is the shallow depth of soil and consequent high percolation loss through the underlying stratum of gravel.

Duty of Water Investigations at Coaldale Alberta, 1913 to 1921

A necessary part of investigations for the determination of a practical duty of water is the carrying on of experimental work under ordinary field conditions in accordance with methods that can be used by the average farmer. Work of this character has been conducted since 1913 on a number of farms in the Coaldale district. Surveyed tracts, varying in size from three to fifty acres, were set aside by the farmers. Irrigation specialists planned the layout of the ditches on these tracts, measured the water applied and generally assisted the farmers in the irrigation of their crops. In the course of this work the farmers were made acquainted with the best practical methods of irrigating their lands and, at the same time, valuable information was obtained by the department regarding the results following the application of water under field conditions. This information is a very useful supplement to the data collected at the experimental stations where the work is necessarily confined to small test plots.

In selecting the tracts at Coaldale the following requirements were kept in mind:—

1. The location and size of the tract should be such that the water applied to any adjacent field would have no influence upon the crop grown on the tract under investigation.

2. The general topography of the tract should be such as would permit of the accurate measurement of the water supplied to and wasted from the tract.

3. The tract should be as near Coaldale as possible so as to permit of one engineer looking after several farms.

Cippoletti weirs and rating flumes were installed for the measurement of the supply and waste water. Each measuring device was equipped, during the period of each irrigation, with an automatic water-stage register in order to obtain a continuous gauge height record.

The yields and area of each field were measured by the engineer.

As most of the farms selected had telephones, the engineer had little difficulty in ascertaining the exact date upon which a farmer would commence irrigating and he could, therefore, place the gauges in time to record the first flow of water.

Temperature, evaporation and precipitation records were kept from April 1 to September 30 in each year Soil moisture tests were made on each tract at the beginning and end of each season's growth. By these tests the moisture content of the soil was determined to a depth of six feet.

Table No. 1 shows the average total depth of water received (irrigation plus precipitation) by the Coaldale tracts, 1913-21, inclusive. The average total depth received by the grain crops is 1 51 feet, the average duty of water for grains is 0·60 foot. For alfalfa and grasses, the average total depth received is 2 00 feet, the average duty for forage crops is 1·22 feet For all tracts under observation, alfalfa, grass, and grains, the average total depth received is 1 95 feet, the average duty for all these crops is 1 16 feet. Of the 140 individual observations which go to make up the average duty of 1 16 feet, 81 are on alfalfa, 26 on wheat, 15 on barley and 6 on timothy 38 per cent grain crops and 62 per cent forage crops.

TABLE No. 1—SHOWING DEPTH OF WATER USED ON COALDALE TRACTS, 1913 TO 1921

Crop	1913			1914			1915			1916			1917		
	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received
Alfalfa	1·70	0·98	2·68	2·11	0·57	2·68	0·68	1·32	2·00	0·41	1·56	1·97	1·31	0·68	1·99
Timothy	0·85	0·98	1·83				1·28	1·32	2·60	0·33	1·56	1·89	1·48	0·71	2·19
Wheat	0·74	0·98	1·72				0·22	1·32	1·54	0·00	1·73	1·72	0·78	0·41	1·19
Oats				1·49	0·57	2·06	0·00	1·32	1·32	0·00	1·73	1·73			
Barley				1·25	0·57	1·82	0·00	1·32	1·32	0·00	1·56	1·56			
Averages for all tracts	1·15	0·98	2·13	1·84	0·57	2·41	0·57	1·32	1·89	0·28	1·56	1·84	1·19	0·65	1·83

Crop	1918			1919			1920			1921			Average 1913 to 1921			
	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	Depth of water applied	Precipitation	Total depth received	No. of fields
Alfalfa	2·00	0·31	2·31	1·66	0·47	2·13	1·31	0·81	2·12	1·59	0·46	2·05	1·42	0·80	2·22	81
Timothy	1·30	0·30	1·60	1·25	0·25	1·50	0·80	0·78	1·58	0·35	0·36	0·71	1·02	0·76	1·78	12
Wheat	1·16	0·29	1·45	1·18	0·38	1·56	0·47	0·81	1·28	0·86	0·48	1·34	0·78	0·80	1·58	28
Oats	1·04	0·28	1·32	1·15	0·43	1·57	0·55	0·80	1·35	0·70	0·43	1·13	0·80	0·79	1·59	15
Barley													0·21	1·15	1·36	6
Averages for all tracts	1·70	0·30	2·00	1·33	0·43	1·76	1·11	0·81	1·92	1·30	0·46	1·76	1·16	0·79	1·95	140 (Total)

TABLE NO. 2—WATER USED BY ALFALFA AND TIMOTHY TRACTS EACH YEAR 1913 TO 1921: COALDALE, ALBERTA

Plot No.	Year	Crop	Depth of Water Applied	Precipitation	Total Depth Received	Yield per Acre	
303	1913	Alfalfa	1·71	0·98	2·69	4·70	
	1914		·39	0·57	1·86	4·21	
	1915		0·45	1·32	1·77	3·96	
	1916		1·83	1·56	3·39	2·91	
	1917			0·72		3·03	Flooded by waste water
	1918		2·05	0·31	2·36	2·73	
	1919		1·78	0·64	2·42	4·11	
	1920		0·84	0·81	·65	2·46	First irrigation too late
	1921		0·97	0·44	1·41	2·13	
Average..					2·19	3·36	
304	1913	Alfalfa	1·70	0·98	2·68	4·40	
	1914		1·70	0·57	2·27	4·67	
	1915		·03	1·32	2·35	4·84	
	1916		0·00	·56	1·58	3·18	
	1917		0·79	0·70	1·49	2·46	Irrigation too late.
	1918		·75	0·30	2·05	2·03	Second irrigation too late
	1919		1·46	0·46	1·92	4·05	
	1920		1·07	0·79	1·86	4·39	
	1921		1·44	0·45	1·89	3·94	
Average					2·01	3·77	
306	1914	Alfalfa	1·66	0·57	2·23		Seeded
	1915		0·39	1·32	·71	3·09	
	1916		0·76	1·56	2·32	3·19	
	1917		1·68	0·70	2·38	2·65	One irrigation too heavy
	1918		1·89	0·27	2·16	3·26	
	1919		1·10	0·46	1·02	4·24	
	1920		1·26	0·81	2·07	4·00	
	1921		1·46	0·45	1·91	4·00	
Average					2·05	3·49	
310	1914	Alfalfa.	·05	0·57	2·28		Seeded
	1915		2·20	1·32	3·52	1·64	
	1916		0·00	1·56	1·56	2·48	
	1917		0·00	0·72	0·72	1·48	No water for irrigation.
	1918		1·35	0·30	1·65	3·99	
	1919		1·86	0·46	2·32	4·92	
	1920		·21	0·83	2·04	2·92	Poor irrigation.
	1921		·28	0·45	1·73	2·63	
Average					1·97	2·87	
312	1914	Alfalfa.	2·61	0·57	3·18		Seeded
	1915		0·84	1·32	2·16	1·91	
	1916		0·00	1·56	1·66	1·5[illegible]	
	1917		1·79	0·66	2·45	2·24	
	1918		1·22	0·33	1·55	2·10	
	1919		·57	0·46	2·03	4·37	
	1920		1·38	0·81	2·19	3·42	
	1921		·44	0·45	1·89	2·90	
Average..					2·[illegible]3	2·64	
313	1914	Alfalfa.	1·61	0·57	2·18		Seeded No record in 1916
	1915						
	1916		0·00	1·56	1·56	3·46	
	1917		1·03	0·66	1·69	4·13	Two light irrigations.
	1918		2·28	0·33	2·61	3·46	
	1919		1·65	0·46	2·11	4·86	
	1920		1·15	0·83	1·98	4·55	
	1921		1·83	0·53	2·36		

TABLE No. 2—WATER USED BY ALFALFA AND TIMOTHY TRACTS EACH YEAR 1913 TO 1921, COALDALE, ALBERTA—*Concluded*

Plot No.	Year	Crop	Depth of Water Applied	Precipitation	Total Depth Received	Yield per Acre	
Average					2·07	3·89	
314	1914	Alfalfa	1·91	0·57	2·48		Seeded
	1915		1·59	1·32	1·91	2·60	
	1916		0·00	1·56	1·56	2·60	
	1917		0·00	0·72	0·72	2·51	Not irrigated
	1918		2·31	0·33	2·64	4·32	
	1919		2·48	0·46	2·94	3·99	
	1920		2·21	0·83	3·04	4·96	
	1921		1·21	0·45	1·66	3·68	
Average					2·12	3·52	
315	1914	Alfalfa	2·13	0·57	2·70		Seeded
	1915		0·20	1·32	1·52	2·04	
	1916		0·00	1·56	1·56	2·69	
	1917		1·03	0·66	1·69	2·38	
	1918		2·81	0·34	3·15	4·37	
	1919		2·06	0·43	2·49	3·83	
	1920		1·64	0·81	2·45	3·73	
	1921		2·15	0·45	2·60	3·38	
Average					2·27	3·20	
324	1918	Alfalfa	2·06	0·30	2·36	3·31	
	1919		1·74	0·46	2·20	4·82	
	1920		1·73	0·81	2·54	5·07	
	1921		1·51	0·45	1·96	3·93	
Average					2·26	4·28	
329	1919	Alfalfa	1·40	0·46	1·86	2·49	
	1920		0·64	0·81	1·45	2·97	Flooded by waste water
	1921		2·03	0·45	2·48	2·72	Uneven irrigation.
Average.					1·93	2·73	
334	1919	Alfalfa	1·25	0·46	1·71	2·71	
	1920		0·71	0·79	1·50	2·79	
	1921		1·96	0·53	2·49	3·29	
Average					1·90	2·93	
305	1914	Alfalfa and Timothy	2·98	0·57	3·55	2·76	
	1915		0·00	1·32	1·32	4·15	
	1916		1·09	1·56	2·65	2·63	
	1917		1·56	0·70	2·26	3·53	
	1918		2·32	0·30	2·62	4·94	
	1919		1·46	0·46	1·92	5·17	
	1920		1·86	0·81	2·67	4·66	
	1921		1·74	0·45	2·19	4·22	
Average					2·40	4·01	
306	1914	Timothy	2·28	0·57	2·85		Seeded.
	1915		1·40	1·32	2·72	1·60	
	1916		0·37	1·56	1·93	1·00	
	1917		1·99	0·72	2·71	1·33	
	1918		1·56	0·33	1·89	0·38	Sod bound and pastured
	1919		1·25	0·35	1·60	0·42	
	1920		0·80	0·78	1·58	1·74	
	1921		0·35	0·36	0·71	1·03	
Average..					1·99	1·06	

Table No. 2 gives a history of each of the thirteen fields under forage crops. The average yield in tons per acre during the period of years for which records are available on each field will be found to vary from 2·64 tons on field 312 to 4·28 tons on field 324. This variation in yield is due to the difference in the stand of crop, the skill of the irrigator and the type of soil. The average yield of 4·28 tons per acre from field 324 was produced with an average depth of water of 2·26 feet, only 0·13 foot more water than was used in field 312.

Results of investigations at the Brooks Experiment Station have indicated that the best depth per irrigation for alfalfa is about six inches and that with this depth per irrigation a yield of 3½ tons of alfalfa per acre used a total depth of approximately 1·70 feet of water. The average yield of the Coaldale alfalfa tracts from 1913 to 1921 is nearly 3¼ tons per acre, but the total depth of water used in producing this yield was 2·22 feet, applied in irrigations of an average depth of about 9 inches. Therefore, the Coaldale tracts have used approximately *32 per cent* more water than the Brooks plots to produce a given yield. If 6 inches is the economical depth per irrigation, the Coaldale farmers in applying 9 inches per irrigation are losing 3 inches or 33⅓ per cent of each irrigation by deep percolation. It is not to be expected that the general field use of water will ever be quite as economical as that of the Experiment station, but wastage can be greatly reduced by applying the water in lighter and more frequent irrigations.

TABLE No. 3—SHOWING AVERAGE IRRIGATING HEAD USED AND ACREAGE IRRIGATED (PER 24 HOURS) COALDALE, ALBERTA, 1921

Crop		Average Depth Applied per Irrigation	Acres Irrigated per 24 hours	Average Irrigating Head Used
		Ft.		Ft.
Alfalfa		0·83	4·20	1·95
Timothy		0·35	2·88	0·84
Grains		0·67	5·52	1·47
Average all tracts, 1921		0·78	4·30	1·82
Average for all tracts	1920	0·68	6·46	2·10
	1919	0·78	4·25	1·81
	1918	0·90	4·43	2·39
	1917	1·15	4·93	2·58
	1916	0·74	5·34	2·49
	1915	0·88	5·20	2·11
	1914	0·86	4·03	2·27
	1913	0·72	6·06	2·39
Average 1913 to 1921		0·81	5·01	2·22

Table No. 3 shows the average depth of water applied per irrigation, the irrigating head used, and the acreage irrigated per 24 hours, for all tracts under observation during the period 1913-21.

The farmers have irrigated 5·01 acres per day with a head of 2·22 feet, applying 9·7 inches (0·81 foot) per irrigation.

Theoretically, an irrigating head of 2·22 second-feet will deliver 53 acre-inches in 24 hours. At this rate, if applied in six-inch irrigations, this amount should cover approximately nine acres, but instead of covering this area the farmers have only been covering five acres per day. They have been losing too large a percentage of their irrigation water by percolation and surface waste. The surface waste loss may

be lessened by more careful leveling of the land and better supervision of the irrigations. The percolation waste may be decreased by applying the water in lighter irrigations. Many irrigators overrate the water-holding capacity of the soil and the power of capillarity to return appreciable quantities of water to the root zone.

With a better general understanding of the water-holding capacities of soils as outlined under Section 3 of this bulletin, irrigation farmers should be able to save much of the water now lost by percolation and to raise the average area irrigated per day, from five towards the possible nine acres.

TABLE No. 4—EVAPORATION IN INCHES FROM A FREE WATER SURFACE, COALDALE, ALBERTA, 1915 to 1921

—	1915	1916	1917	1918	1919	1920	1921	Average 1915 to 1921
April	5·68	1·51	2·65	3·20	6·59	3·31	2·05	3·56
May	4·28	5·12	4·63	6·76	6·20	5·66	3·99	5·08
June	2·26	4·88	5·78	7·88	7·80	6·47	6·88	5·96
July	4·38	6·20	9·20	7·68	8·12	6·92	6·55	7·01
August	4·97	4·70	5·23	6·79	6·91	5·76	6·09	5·78
September	2·93	3·59	4·35	3·76	3·81	4·80	4·28	3·44
Totals	24·50	25·50	31·94	36·07	37·93	32·94	29·29	30·73

TABLE No. 5—MEAN MONTHLY TEMPERATURES AND PRECIPITATION 1913-21, INCLUSIVE, COALDALE, ALBERTA

—	1913		1914		1915		1916		1917	
	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
April	43·8	0·52	4·24	0·54	50·0	0·00	44·3	0·26	39·2	0·70
May	45·4	1·70	51·7	0·33	61·1	2·99	48·6	4·12	49·7	0·86
June	61·0	4·70	58·6	1·67	54·7	5·31	56·4	3·62	66·4	2·11
July	61·4	1·29	67·0	0·68	59·3	5·15	63·3	2·47	68·5	0·29
August	63·4	1·93	62·5	2·58	67·2	0·28	60·8	3·25	63·3	1·88
September	54·9	1·65	53·5	1·05	50·4	2·11	53·6	4·79	55·1	2·82
Average temperature and total precipitation	55·5	11·79	55·9	6·85	55·4	15·84	54·5	18·71	55·4	8·66

	1918		1919		1920		1921		Average 1913-1921	
	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.	Temp.	Precip.
April	42·8	0·15	45·4	0·53	31·1	3·54	41·2	0·54	42·2	0·75
May	44·0	1·03	49·0	1·86	47·6	1·59	51·0	1·28	48·0	1·75
June	63·0	0·65	58·3	0·66	57·6	1·09	62·8	0·86	58·7	2·32
July	64·8	0·93	65·9	1·27	69·0	3·21	64·6	2·17	64·8	1·94
August	63·5	1·23	66·7	1·20	66·1	0·29	62·7	0·56	64·3	1·47
September	57·4	0·41	54·8	2·14	55·4	0·31	50·4	1·31	53·9	1·83
Average temperature and total precipitation	55·8	4·40	56·7	7·66	54·7	10·03	55·4	6·61	55·6	10·06

TABLE No. 6

Year	302	304	306	310	312	313	314	315	324	329	334	308
1913	4·70	4·40										
1914	4·21	4·67										2·78
1915	3·96	4·84	3·09	1·64	1·91		2·60	2·04				4·[illegible]6
1916	2·91	3·16	3·19	2·48	1·51	2·46	2·60	2·69				2·03
1917	3·03	2·46	2·65	1·48	2·24	4·13	3·51	2·38				3·63
1918	2·73	2·03	3·26	3·96	2·10	3·46	4·32	4·37	3·31			4·94
1919	4·11	4·05	4·24	4·92	4·37	4·86	3·99	3·83	4·82	2·49	2·71	5·[illegible]7
1920	2·46	4·39	4·08	2·92	3·42	4·55	4·96	3·73	5·07	2·97	2·79	4·78
1921	2·13	3·94	4·00	2·63	2·96		3·68	3·38	3·93	2·72	3·29	4·22
Total	30·24	33·96	24·51	20·06	18·51	19·46	24·86	22·42	17·13	8·18	8·79	32·2[illegible]
Average	3·36	3·77	3·50	2·87	2·64	3·89	3·52	3·20	4·28	2·73	2·93	4·03

Table No. 6 gives a general summary of the yields in tons per acre from the Coaldale alfalfa fields. Plot 324 has produced the highest yields for the last four years, averaging 4·28 tons per acre. This tract received an average depth of 2·26 feet of water. For all fields the average yield over the entire period is 3·38 tons.

The following table shows the average yields and depths of water received for the tracts at Coaldale and the average yields and depths used for the plots at Ronalane and Brooks.

Crops	Coaldale		Ronalane		Brooks	
	Average yield	Average depth received	Average maximum yield	Average total depth used	Average maximum yield	Average total depth used
	tons	feet	tons	feet	tons	feet
Alfalfa	3·38	2·22	3·25	2·40	5·70	2·62
			bush.		bush.	
Peas			43·5	2·37	58·0	2·25
Wheat		1·58	46·0	2·20	43·5	1·90
Barley		1·36	53·0	1·75	52·0	1·67
Oats		1·59	81·0	1·82	93·0	1·62
					tons	
Grass hay					1·63	1·50
					bush.	
Alfalfa seed					7·0	1·46
Potatoes			35·5	1·65	295·0	1·46
					tons	
Corn					21·5	1·36
					bush.	
Flax					21·5	1·34

The above table gives a comparison of the summaries of the Coaldale, Ronalane and Brooks investigations. The Coaldale data are from large fields, the Ronalane and Brooks data from experimental plots.

SUMMARIES

Coaldale.—The figures shown for Coaldale represent the average depth of water applied by the farmers to four different crops under ordinary field conditions. They are valuable as indicating what the duty of water may be expected to be under field conditions in a project similarly situated when surface and percolation losses are taken into consideration. The Coaldale data show that the average farmer applies an excessive depth per irrigation and allows too much water to escape by percolation and surface waste into the canals and local drainage. Lighter and more frequent irrigations would have prevented most of this waste.

Ronalane.—The figures shown for Ronalane represent the total depths of water used to grow the crops on a rather shallow soil, two to four feet deep, on which manure, rather than leguminous crops, has been used to maintain the fertility of the soil.

Brooks.—The figures shown for Brooks represent the average total depth used to produce maximum yields of crops grown under varying conditions of soil fertility. These figures indicate the amounts of water needed to produce maximum yields under what are considered to be nearly ideal irrigation conditions, where the correct amount of water is applied in irrigations of proper depth and frequency. They are applicable to districts having soil and climatic conditions similar to those at the Brooks station.

The depths used at Ronalane are considerably greater than for similar crops at Brooks, because of the smaller water-holding capacity of the Ronalane soil and a consequent greater proportional loss by deep percolation of the water applied.

The depths at Coaldale are considerably greater than at Brooks due to the large amounts of water lost by excessive depths per irrigation and surface waste.

The figures for any crop at the three places should not be averaged for the reason that the figures for grains at Brooks and Ronalane represent the total depths used in producing maximum crop yields under two entirely different conditions of soil and that the figures for grains at Coaldale represent only what was received by the crop, being usually an insufficient amount and producing only fair yields.

SECTION 3

Water Holding Capacity of Soils

The farmer will learn to know when his crops need water by the general appearance of the plants and by an examination of the soil as described in section 2 of this bulletin under the heading "Time of Irrigation." It would be quite impossible for him to apply the elaborate methods of soil moisture determination which are described in the following pages. These methods are only applicable to experimental stations. In view, however, of the keen interest that has been displayed by irrigators in the subject of the water-holding capacity of soils, and of the commanding importance of this subject in any thorough study of the factors affecting the duty of water, this section has been added to the bulletin.

Water in the Soil.—Water is found in the soil in three conditions, hygroscopic, capillary and gravitational.

Hygroscopic Water. Soils artificially dried so as to deprive them of all their moisture, when exposed to a moist atmosphere will absorb a certain amount of water vapour, the amount depending upon their texture (i.e., proportion of sand, silt and clay), upon their colloidal content (i.e., proportion of humus, ferric hydrate, clay and lime), and upon their temperature. In general sandy soils will absorb less than clay soils and soils poor in humus less than soils rich in humus. The finer the soil texture the larger the amount of water vapour absorbed. The sandy soil at Strathmore absorbed about two per cent, the clay loam soil at Coaldale about seven per cent. This moisture, which is known as hygroscopic water, is regarded as having a beneficial action in bringing into solution some of the plant food material held in the soil, on account of its close contact with the soil particles, but investigators (studying the problem from both the laboratory and field points of view) have reached the conclusion that plants are not able to use this moisture for growth.

Capillary Water.—Capillary water is that part of the soil water which is held or moves in the soil against gravity by surface tension—the same force that causes kerosene to move along a lamp wick, or ink to enter a blotter. This water adheres to the soil particles in more or less thickened films and moves freely through the soil in any direction as influenced by the two forces, gravity and surface tension.

As some portion of the soil becomes drier, due to the evaporation of water from the soil surface or to the absorption of water by the root hairs of plants, the film of water surrounding the soil particles at that point becomes thinner, and exerting a stronger force, just as the rubber in a rubber band becomes thinner and exerts a stronger pull when stretched, draws some water from the surrounding soil particles where the film is thicker and of lower tension. The film surrounding these drier particles in turn draws from the more moist particles adjacent and so on, moving the water from the moist to the drier portions of the soil. If the absorption or use of water at any point in the soil ceases, the capillary movement towards that point will cease as soon as its surrounding soil particles have received sufficient water so that the films covering them no longer exert a stronger pull than the films surrounding the other soil particles.

When water is applied to the bottom of a column of dry soil it will be observed to rise through the soil, the extent and rapidity of this rise depending upon the soil texture. Water will rise faster but to a less height in a coarse sand than in a fine sand.

From the standpoint of crop production the farmer is interested almost wholly with the water that is held by capillarity within the zone occupied by plant roots. The movement of water through soils by capillarity is so slow as to be of relatively little value in raising sufficient quantities of water from sub-root zone regions to supply the needs of crops during the season of greatest daily use. Grain on the Strathmore plots, where the soil is a light sandy loam, suffered severely during periods of drouth, even though there were standing water at a depth of six feet. The grain roots, penetrating to depths of three to four feet, had depleted the moisture content of that depth to the wilting point and still the amount of water raised through the sand from the six-foot depth by capillarity was insufficient to supply the needs of the plants.

Studies made on several fields near Gleichen, Alberta, during the summer of 1915, showed an exhaustion of the soil moisture to a depth of three feet, beyond which the soil moisture content rapidly increased.

Gravitational Water.—As a soil becomes more and more nearly filled with water a point is reached, known as the maximum water holding capacity, where the force of gravity exerts a stronger pull than the surface tension of the water films around the soil grains. Water then begins to move downward into the soil until it either reaches the water table below or a point where the forces of gravity and surface tension are in equilibrium. This downward movement of gravitational water is commonly referred to as percolation.

Knowledge of Water-Holding Capacity Important

It is of the utmost importance that the water user should have a knowledge of the water-holding capacity of the different soil types common to his land. In order that he may intelligently plan his irrigation programme he needs to know how much water can be stored in each class of soil for the use of crops, and how much can be economically applied per irrigation.

Some of the light sandy soils experimented with would retain only about one inch of available water per foot in depth, while some of the silt loam soils retained as high as three times this amount.

When irrigations are applied of a depth in excess of the water-holding capacity of any soil there is a loss due to deep percolation. This loss is harmful in that it tends to raise the general level of the ground water, leaches out soluble plant foods and causes waterlogging and alkali saturation of lands in the lower-lying portions of the district.

Soil studies, dealing especially with water-holding capacity, have been carried on by this department since 1914, covering many of the soil types common to southern Alberta. The results of these studies are shown in the following table:—

TABLE SHOWING WATER HOLDING CAPACITY OF SOUTHERN ALBERTA SOILS

1	2	3	4	5	6	7	8	9	10
Type of soil	Depth	Hygroscopic coefficient	Wilting coefficient	Weight of a cubic foot of dry soil	Amount of water held when soil is saturated i.e. all pore space filled with water	Maximum capillary capacity	Non-available water	Maximum amount of available water held by soils with free drainage	Optimum available water content
	feet	%	%	lbs.	inches	inches	inches	inches	
Medium sand	1	2·00	2·94	89	5·83	2·05	0·50	1·55	
	2	1·80	2·65	90	5·36	1·55	0·46	1·09	
	3	1·80	2·65	91	4·55	1·58	0·46	1·12	
	4	1·80	2·65	91	4·20	1·58	0·46	1·12	
	5	2·00	2·94	91	3·85	2·10	0·51	1·59	
	6	2·20	3·23	91	3·50	2·10	0·56	1·54	
Total ...					27·29	10·96	2·95	8·01	8 to 13 ins.
Sandy clay	1	4·10	6·03	89	5·65	3·04	1·03	2·01	
	2	3·50	5·14	90	4·50	3·29	0·89	2·40	
	3	4·10	6·03	92	4·43	3·54	1·07	2·47	
	4	4·10	6·03	92	4·24	3·54	1·07	2·47	
	5	4·10	6·03	92	4·07	3·54	1·07	2·47	
	6	4·70	6·92	92	3·89	4·42	1·23	3·20	
Total.					26·78	22·27	6·35	15·92	5 to 10 ins.
Clay loam (316)	1	6·70	9·86	74	6·97	4·27	1·40	2·87	
	2	6·32	9·30	77	6·81	4·15	1·38	2·77	
	3	5·82	8·37	80	6·30	4·15	1·29	2·86	
	4	7·30	10·73	83	6·22	4·00	1·71	2·29	
	5	7·75	11·40	88	6·45	4·47	1·88	2·59	
	6	7·62	11·20	89	6·67	4·63	1·92	2·71	
Total.					39·42	25·67	9·58	16·09	8 to 14 ins.
Clay loam (306)	1	6·90	10·15	70	6·73	4·04	1·50	2·54	
	2	4·92	7·23	78	6·60	4·20	1·08	3·12	
	3	4·88	7·18	86	6·28	4·13	1·19	2·94	
	4	4·92	7·23	95	6·03	4·38	1·32	3·06	
	5	5·32	7·82	100	5·19	4·43	1·50	2·95	
	6	5·20	7·65	102	4·32	4·32	1·50	2·82	
Total.					35·15	25·50	8·09	17·41	6 to 13 ins.
Silt loam. .	1	2·70	3·90	78	5·70	4·00	0·58	3·42	
	2	4·90	7·20	85	6·20	4·60	1·17	3·65	
	3	4·10	6·00	85	6·20	4·80	0·98	3·82	
	4	3·90	5·70	85	6·20	4·80	0·93	3·87	
	5	3·70	5·40	85	6·20	4·80	0·88	3·92	
	6	3·50	5·10	85	6·20	4·80	0·83	3·97	
Total. .					36·70	28·00	5·37	22·63	9 to 17 ins.
Loam	1	3·40	5·10	75	5·78	3·70	0·72	2·98	
	2	3·40	5·10	90	4·16	3·70	0·87	2·83	
	3	3·40	5·10	90	4·34	3·70	0·87	2·83	
	4, 5, 6	Gravel							
Total					14·28	11·10	2·46	8·64	3 to 6 ins.

Columns (1) and (2) give the type of soil and depth.

Column (3) gives the hygroscopic water content in per cent of the dry weight of soil. This is known as the hygroscopic coefficient.

Column (4) gives the wilting coefficient in per cent of the dry weight of soil. These figures represent the percentage of moisture the soil will contain when plants begin to wilt. When the percentage drops below the wilting point the capillary movement is so sluggish that the plants cannot obtain sufficient moisture to provide for normal growth.

Column (5) gives the weight in pounds of a cubic foot of soil in its natural condition. It ranges from 70 pounds for a clay loam soil containing considerable humus to 100 pounds for fine sands.

Column (6) gives the depth of water in inches that a soil will hold when saturated, that is when all the pore space of that soil is occupied by water and all air is excluded. This condition would only obtain where the soil was water-logged. The depths in this column indicate the pore space in the various soils.

Column (7) gives the maximum capillary capacity of the soil as determined by soil moisture tests made after heavy rains and irrigations. It represents the total amount of water a soil is capable of retaining against gravity under free drainage conditions.

Column (8) gives the non-available water content. It represents that amount of water which the soil will still contain when plants begin to wilt.

Column (9) gives the maximum amount of water available for plant use which a soil is capable of retaining against the pull of gravity under free drainage conditions. It is calculated by subtracting the figures of column 8 from the figures of column 7. It represents the amount of water which could be stored for plant use and varies from 8 inches in sand to 32 inches in silt loam for a six foot depth.

Column (10) gives the optimum available water content. The figures shown represent the usable water contained when optimum conditions for plant growth prevail. It has been determined by experiments (Hilgard) that conditions are most favourable for plant growth when from 40 to 60 per cent of the pore space of the soil is filled with water, that is, the pore space should contain about half water and half air.

When more than 60 per cent of the pore space of the soil is occupied by water, conditions become unfavourable for growth, the soil becomes cold, the activities of the bacteria which break down organic matter are restricted, plants have great difficulty in securing enough oxygen for their needs from the soil air and, on account of the high water content and consequent greater dilution of the soil solution, must transpire excessive amounts of water to secure the plant foods they require.

When less than 40 per cent of the pore space of the soil is occupied with water, conditions become unfavourable for growth as the low water content makes it difficult for the plant to secure sufficient moisture for normal development.

It should be the aim of the irrigator to keep the moisture content of the soil within the optimum range. A study of the silt loam soil data as given in the preceding table shows that while this soil could contain 22.63 inches of water (column 9), this quantity would be too much, the soil would be too wet. Seventeen inches represent the maximum amount of available water this soil should contain and as 9 inches is the least amount it should contain, it follows that in a six foot depth the irrigator *could store 8 inches of water for the use of the crop.* The ideal practice then would be to bring the water content up to the highest optimum figure and then irrigate as often as necessary to keep the moisture content within optimum range. For grains then, which feed to a depth of about four feet, *a five- or six-inch irrigation should be applied to this soil whenever the total water content to a depth of six feet drops to about 14 inches.* (9 inches lower optimum range of available water plus 5.37 inches non-available water=14.37 inches total water content.)

A study of the data presented for the medium sand soil at Strathmore shows that while the silt loam soil has a maximum available water capacity of 22 63 inches for a six-foot depth, the sand only has a capacity of 8 01 inches, just a little better than one-third that of the loam. The figures given in column 10 for the sand show an optimum range of 8 to 13 inches Therefore, under free drainage conditions, this sand *never could hold* the optimum amount of water, it would never be too wet.

Again, assuming that grain is grown on this soil, which has a capacity of only 4 88 inches for the depth to which grain roots usually feed, irrigations of depths not to exceed four inches each should be applied with sufficient frequency to maintain the total available water content as near 8 inches as possible The danger would not be in getting the sandy soil too wet, but in applying too much per irrigation. If a six-inch irrigation were applied, at least 30 per cent of it would be lost to the grain by percolation.

With the loam soil, conditions would be reversed. Because of its ability to retain large quantities of water it would get too wet for an optimum crop before any appreciable loss would occur by percolation.

In the sand then, between its wilting point, where the total water content is only 2 95 inches in a six-foot depth, and its maximum available capillary capacity, where the water content to the same depth is 8 01 inches, there is storage for *only 5 06* inches This entire amount is held under sub-optimum conditions, for as explained previously, the optimum water content for the sand would range from 8 to 13 inches providing the sand could retain that amount.

The silt loam soil of the Brooks farm, between its wilting point, at which the water content to a six-foot depth is 5 37 inches, and its optimum available capillary capacity, at which the water content is 17 inches, will hold to the above depth 11 63 inches of water

Assuming that the two soils were dried out to their respective wilting points, an irrigator could store 5.06 inches of water in the Strathmore sand and 11 63 inches of water in the Brooks silt loam. In the former soil the entire amount stored would be below the optimum moisture range for that soil, while in the latter soil, only 3 63 inches of the amount of water stored would be below the optimum moisture range, and the remaining 8 inches would be within the optimum range

Using the above data where the crops under irrigation are grain, feeding to a depth of approximately four feet, the storage capacities would be ⅔ of the amount as given for a six-foot depth, as shown by the following table,—

	Below optimum range	Within optimum range	Total
	inches	inches	inches
For sand	3·58	0·00	3 58
For silt loam	2·42	5·33	7 75

From the foregoing data it will be obvious, that for grain crops irrigations of about four inches in depth on the light sandy soils and not exceeding six inches in depth in the silt loam soils, should be applied with sufficient frequency to maintain the moisture content within the range desired.

DEPARTMENT OF THE INTERIOR

RECLAMATION SERVICE.

Plan of

BROOKS IRRIGATION EXPERIMENT STATION.

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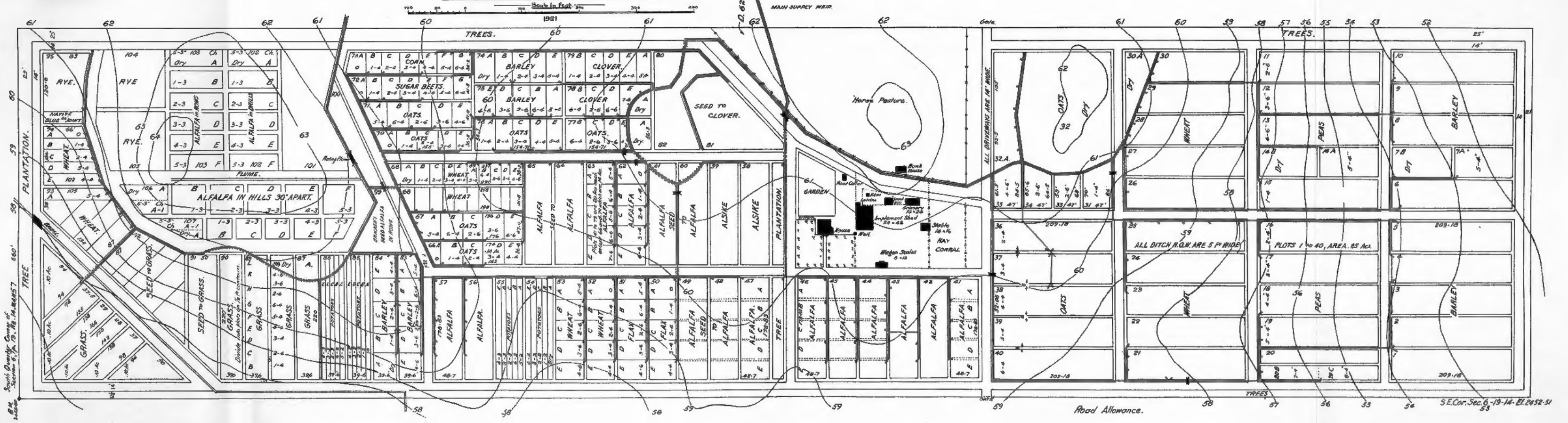

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